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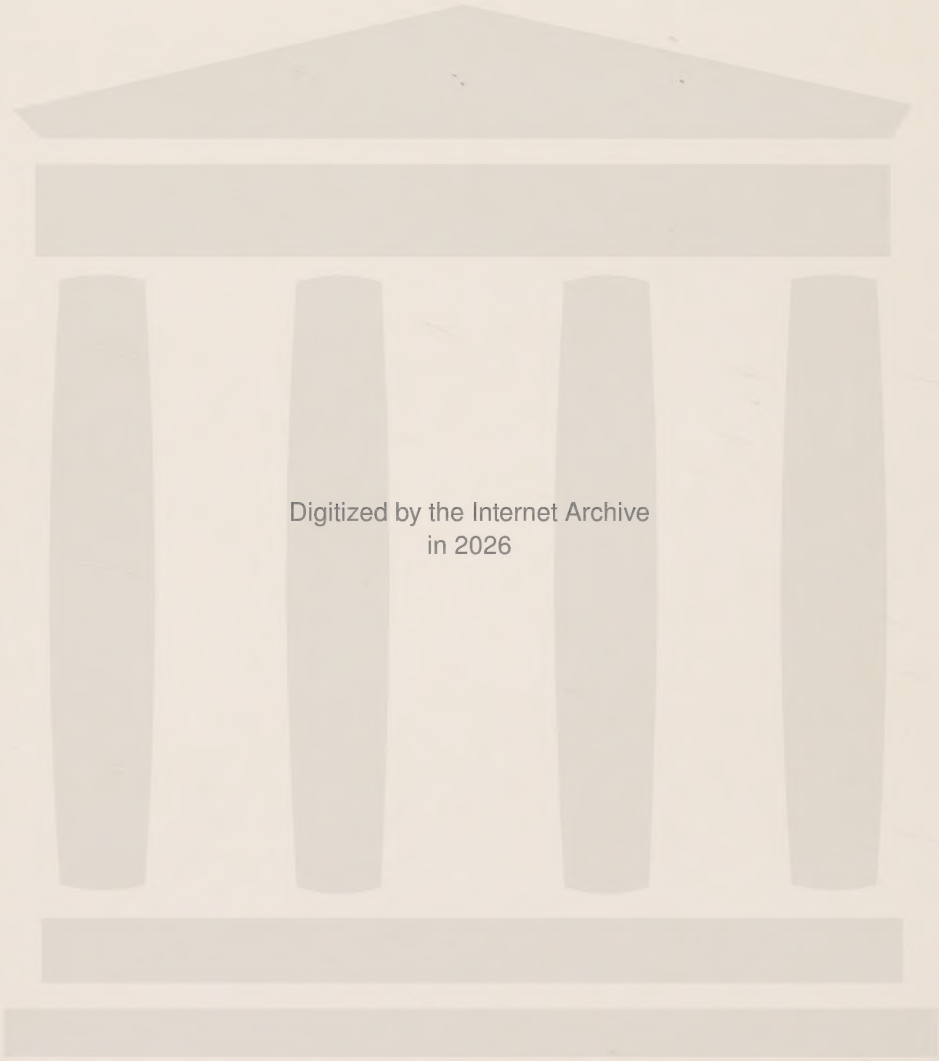

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SEA FISHERIES RESEARCH INSTITUTE

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An annual publication reporting on research of the past calendar year together with a preview of some to be undertaken

Cape Town 1997

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The text was compiled by the editor from contributions made by the following staff members: T. R Akkers, R. J. Anderson, C. G. Attwood, M. Barange, A. C. Cockcroft, J. Coetzee, R. J. M. Crawford, J. H. M. David, P. De Bruyn, J. A. A. De Oliveira, C. M. Duncombe-Rae, M. H. Griffiths, J. C. Groeneveld, J. A. Huggett, L. Hutchings, D. W. Japp, M. Kerstan, F. Le Clus, G. J. Levitt, M. R. Lipinski, D. G. M. Miller, B. A. Mitchell-Innes, Y. C. Melo, C. L. Moloney, D. J. Needham, G. Nelson, A. J. Penney, G. C. Pitcher, A. J. Richardson, B. A. Roel, D. S. Schoeman, L. J. Shannon, A. Share, R. J. Q. Tarr, C. D. van der Lingen, H. M. S. Verheye. The Director of the Sea Fisheries Research Institute, Dr A. I. L. Payne, wrote the introduction and laid down the guidelines.

MISSION OF THE
SEA FISHERIES RESEARCH INSTITUTE

The Sea Fisheries Research Institute advises on the utilization of living marine resources and the conservation of marine ecosystems by conducting and supporting relevant multidisciplinary scientific research and monitoring in the marine environment. Sustainable use and the need to preserve future options regarding the utilization of marine ecosystems and their resources are guiding objectives in the research and advice of the Institute. In order to achieve its goals, the Institute advises and interacts with decision-makers, those involved in fishing, interest groups and the local and international scientific community. The Institute conducts its activities in an open and co-operative manner, functions within the Department of Environmental Affairs and Tourism and strives for excellence in its endeavours.

INTRODUCTION

The Sea Fisheries Research Institute is, during 1996/97, going through the same difficulties as marine research nationally and globally. Attempts to keep its research initiatives at the cutting edge worldwide are being compromised by funding cuts that limit such fundamental requirements as time at sea and the ability to retain expertise in the form of technical and research manpower. The challenges are, however, being met, and what follows in the pages of this publication show, I am sure, both sincere dedication to the objective of scientific excellence and a belief that only quality science (in the Institute's case, natural science) can help South Africa achieve what many other countries are finding increasingly difficult to attain against the backdrop of social and economic reality, namely sustainable utilization of all its marine resources.

Two developments in South Africa have contributed extra major challenges to the generally very experienced research corps of the Sea Fisheries Research Institute. The first of these is the development of a new, broadly acceptable fisheries policy for the country. Inputs by Institute staff to this process in the form of advice and background on international norms have been ongoing for a number of years, but now, with the Policy hopefully about to be enacted, the challenge to implement its various clauses will place additional pressures on the many loyal scientists and technical officers whose understanding of the marine resources is great enough to see what can and cannot be achieved, and how speedily. The second development is the escalating international (and specifically regional) involvement of the Institute scientists. After years of politically-inspired isolation, broken only by a few personal contacts of some of the research staff, there is now a veritable flood of offers of co-operation and requests for assistance which have to be met. Regionally, South Africa is well placed to assist, but the same funding and manpower limitations mentioned earlier preclude us from servicing all requests. With generally healthy industrial fisheries, the prime aim of the Institute is to address challenges at home, but many of the regional fisheries and ecosystem problems are similar to ours, so it would be shortsighted to ignore calls for collaboration from our neighbours.

Despite the pressures referred to above, South Africa, and the Institute in particular, has continued to make sound progress in the international arena and to assist in the hosting of international conferences in the country. The culmination of the third five-year phase of the Benguela Ecology Programme saw the hosting of a fine symposium in Cape Town in November 1996. Institute input to both science and organization of that event was notable, and the Institute editor is currently compiling what will no doubt be yet another excellent volume of marine research papers. Associated with that, South Africa celebrated 100 years of marine science (the first Director of Sea Fisheries took office in 1896), and a special suite of presentations and papers was commissioned for the occasion. Again, Institute scientists were at the forefront of the activity, and again the Institute is responsible for editing the proceedings. International conferences on penguins and cephalopods have been (former) or are to be held soon (latter) in Cape Town, once more involving extensive input from Institute scientists. Involvement away from South Africa has also been extensive, Institute scientists being involved in making notable scientific input to symposia and workshops on subject matter as diverse as currents, harmful algal blooms, seals, fisheries and ecosystems. In some cases, Institute scientists have played key roles. For instance, in recognition of South Africa's and Sea Fisheries high standing in the CCAMLR scientific community (see later in this publication), a staff member was unanimously elected as chairperson of the CCAMLR Scientific Committee for 1997 and 1998.

Perhaps the most notable regional initiative currently underway and involving scientists from the Institute is the BENEFIT (BENguela, Environment, Fisheries, Interaction & Training) programme. Scientists from Angola, Namibia and South Africa, actively supported by scientists and funds from agencies in Norway and Germany in particular, but many other countries too, are collaborating in an extensive study of the Benguela ecosystem, with particular reference to its marine resources. Training of local expertise is high on the agenda of this initiative, one modelled closely on the highly successful Benguela Ecology Programme referred to earlier. The same three countries, but with input from the USA, Norway and others, are also looking at the viability of commencing a Large Marine Ecosystem study in the region, with the environment rather than the resources as a focus. International funds have been obtained for the feasibility/development stage of that programme.

Up to now, little mention has been made of the actual research highlights of the Sea Fisheries Research Institute. Most of them are covered adequately in the pages that follow, so I will not mention them here in any detail. However, it would be remiss of me not to acknowledge at least the fisheries research advances made in the development of operational management procedures for most of the industrialized fisheries (a stated requirement of the new Fisheries Policy), assessment of chokka squid *Loligo vulgaris reynaudii*, knowledge of the stock health of dusky kob *Argyrosomus japonicus*, in predicting recruitment of pelagic fish and on growth prediction of West Coast rock lobster *Jasus lalandii*. Elsewhere in the marine research field, significant in-house progress has been made in understanding the potential of some of South Africa's seaweeds for commercial exploitation, in linking seabird population trends with pelagic fish abundance, in studying eddies and filaments by real-time observation, in modelling the transport of pelagic fish spawning products, in promoting the importance of marine biodiversity, in particular by studying the relevance of and necessity for Marine Protected Areas, and in reviewing long-term trends of zooplankton off South Africa. None of this work would have been possible without an extremely competent technological development team or the willingness of the network of marine scientific institutions in South Africa to collaborate with Institute scientists.

It is the networking of all marine scientists in South Africa that allowed South African marine science to stay abreast of international research achievements in the years of isolation. It is this same networking of a new generation of committed marine scientists inside and outside the Institute that will ensure the future excellence of marine research in this country.

STUDIES ON RESOURCES

Pelagic fish

The Institute's research on pelagic resources focused on alternative approaches of assessing stocks of anchovy *Engraulis capensis* and sardine *Sardinops sagax* to provide the basis of a new management procedure that addresses their changing status. While the abundance of anchovy was found to be very low during 1996, the sardine resource remained at healthy levels. This resulted in the by-catch of juvenile sardine in the anchovy-directed fishery increasing to levels unaccounted for in the existing management procedure. The new procedure, developed in consultation with the pelagic industry, was to be kept in place until there were clear signs of recovery of the anchovy stock. A feature of the procedure was that a higher proportion of the sardine stock was made available to the canning industry because of the drastic reduction in juvenile sardine mortality resulting from the closure of the anchovy-directed fishing operations for the first half of 1997. The difficulties experienced in the anchovy fishery may lead to an increase in fishing pressure on round herring *Etrumeus whiteheadi*, a non-quota species, which although not as easily caught as anchovy, is suitable for processing into meal and oil. Its status and productivity will be reassessed through a new project developed in close co-operation with scientists at the University of Cape Town.

The 1996 recruit survey was delayed until June and limited to the area from the Orange River mouth to Wilderness. The survey indicated that anchovy recruitment was at its lowest since the inception of acoustic recruitment surveys in 1985, and appeared to have decreased by approximately 80% since the previous year. Supporting evidence for this drastic decline was the significant negative correlation between anchovy recruitment and south-easterly wind strength during the previous summer; as south-easterly winds were stronger than average during the summer of 1995/96, recruitment was expected to be low. Anchovy recruits were found to have a bimodal length distribution with two small peaks, one at 4.5 cm and the other at 8.5 cm caudal length, suggesting that a large portion of the recruits was spawned towards the end of 1995. Sardine recruitment was estimated at 89 000 tons, comparable to recruitment estimates in the 1980s but the second lowest measured over the previous five surveys.

The spawner biomass survey in November 1996 covered the entire spawning area, between Hondeklip Bay and Port Alfred. As was expected from the results of the recruitment survey and from the difficulties encountered by the fishing industry in fulfilling their quotas, the anchovy biomass was the lowest ever estimated (143 000 tons), with the only significant anchovy concentrations being found offshore between Cape Agulhas and Cape Recife. This distributional pattern differs markedly from that found in previous years when most of the population was found on the western Agulhas Bank. Sardine were found mostly inshore between Cape Point and Cape Agulhas, although large concentrations were also recorded in St Francis and Algoa Bays. The biomass of sardine was estimated at just over 500 000 tons, comparable to estimates obtained since 1993. However, the survey revealed very few fish of less than 15 cm caudal length, representing 1 year old fish, a finding consistent with the weak recruitment estimated by the June survey. Recruitment in 1994 was also poor, so the relatively high abundance of sardine can mainly be attributed to a single strong cohort that recruited in 1995.

The sixth pelagic pre-recruit survey was conducted during March 1997. The aim of these surveys is to provide an early indication of

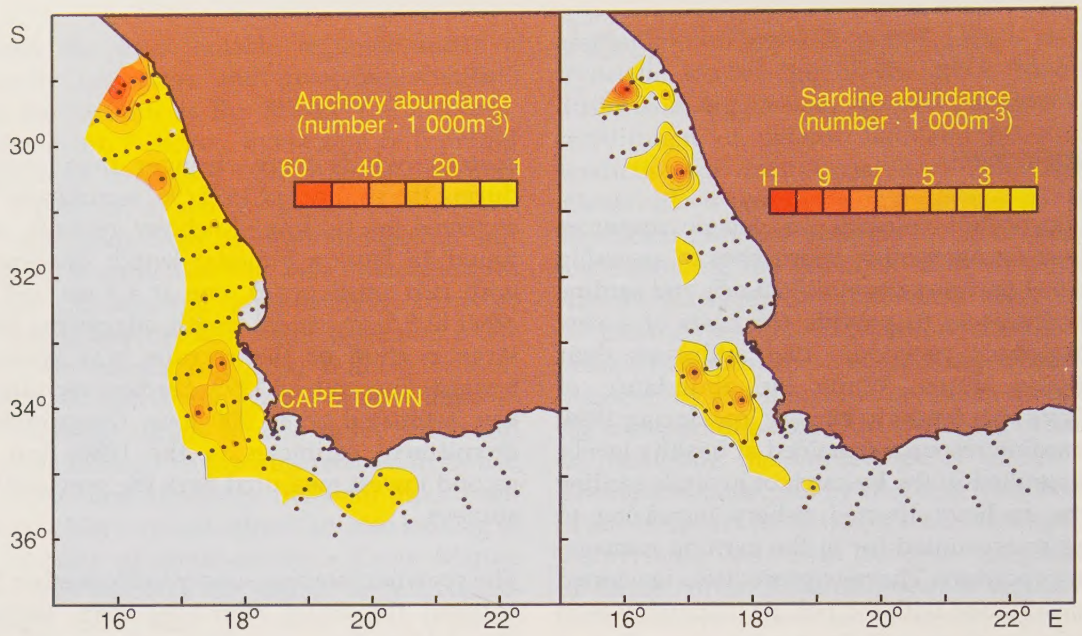

Fig. 1: Spatial distribution of anchovy and sardine pre-recruits during March 1997

anchovy and sardine recruitment, and although the time-series is rather short, the results obtained to date suggest that the pre-recruit abundance index may indeed be useful in predicting recruitment. The survey covered the area from the Orange River to Mossel Bay, corresponding at that time of year to the distribution of fish spawned during the most recent spawning season. As has been the case during previous surveys, anchovy pre-recruits were distributed over the entire West Coast nursery area (Fig. 1), with older, larger pre-recruits found in the north and younger pre-recruits found in the south. Sardine pre-recruits were also located over the West Coast nursery area, but were present at much lower abundances and had a more patchy distribution than anchovy. Very low abundances of anchovy and sardine pre-recruits were observed east of Cape Point, suggesting that the South Coast is not generally used as a nursery area by either species.

Although anchovy pre-recruits were widely distributed over the West Coast nursery area, they were present at relatively low abundances during the 1997 survey. The time-series of pre-recruit abundance index (expressed as the average number of pre-recruits per 1000 m^3 over the West Coast nursery area from the Orange River to Cape Columbine) shows that the high average densities observed during the early 1990s of 30–40 anchovy pre-recruits have now decreased to approximately 10 pre-recruits per 1000 m^3 (Fig. 2). Conversely, the average density of sardine pre-recruits has increased steadily over the duration of the time-series, the value for the 1997 survey being the highest yet recorded. In 1991 and 1992, the ratio of anchovy to sardine pre-recruits over the West Coast nursery area was about 200:1; in 1997, that ratio is 10:1. The declining ratio mirrors the trends observed for the adult anchovy and sardine populations.

At the regional level the Institute co-operated with Namibia in the assessment of their local sardine stock, which recent acoustic surveys had indicated was in a depleted state. An Institute scientist was also invited to participate in an

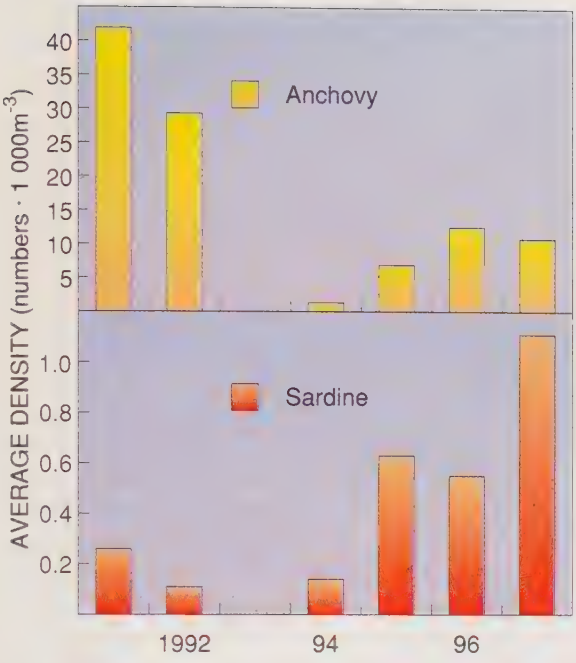

Fig. 2: Time-series of the pre-recruit abundance index

international workshop held in Swakopmund in early 1997 to propose appropriate research and management strategies aimed at enhancing the recovery of the stock, and maintaining it once recovered.

Biological research continued to focus on otolith growth in sardine, the samples being obtained from commercial catches. An interesting finding was that sardine can regulate their growth even after they have reached sexual maturity at the age of two or three, with the result that undersized sardine can grow at increased rates even at older ages if environmental conditions favour growth. This challenges the common perception that the individual growth rate does not increase after the fish have reached maturity. Research is also under way to improve estimates of the age composition of the sardine population. This requires data on the observed length-frequency distributions and the age-length keys from the November surveys, which for some years are unavailable or based on poor information. The methods attempt to correct for biases that arise from applying age-length keys collected in some years and length-frequency data in others. Various statistical methods are being compared, and the assumptions involved in each method, the number of samples required for age information, and optimal ways to interpret the results are being investigated by simulation.

Research on demersal fish resources in 1996/97 was directed at improving assessment techniques and on providing biological, environmental and other data considered necessary for both management and resource assessment. Although the demersal fisheries exploit many different species, research focuses on the three target commercial species for which Total Allowable Catches (*TAC*s) are set, the Cape hakes *Merluccius paradoxus* and *M. capensis*, Agulhas sole *Austroglossus pectoralis* and horse mackerel *Trachurus trachurus capensis*.

The assessment of the Cape hake resources is based on the time-series of catch per unit effort (*cpue*) by commercial trawlers, the assumption being that the catch rate index is proportional to stock size. Availability of the resource may, however, be influenced by many other factors, such as fish aggregating behaviour and environmental perturbations. Interpretation of catch rate indices may also be biased by changes in fishing gear or techniques, yet the *cpue* time-series has been standardized crudely to account for differences in vessel size and power only. For this reason, general linear model (GLM) analyses are being used to calculate a new series of standardized catch rates for the hake fishery. The GLM analyses factor out all effects which can be quantified (e.g. by-catch, vessel, area and seasonal effects), resulting in a standardized *cpue* which more closely reflects biomass trends. Initial results from a selected GLM base case suggest that the West Coast hake resource biomass may not be increasing at the rate indicated by the *cpue* time-series (Fig. 3). Similar

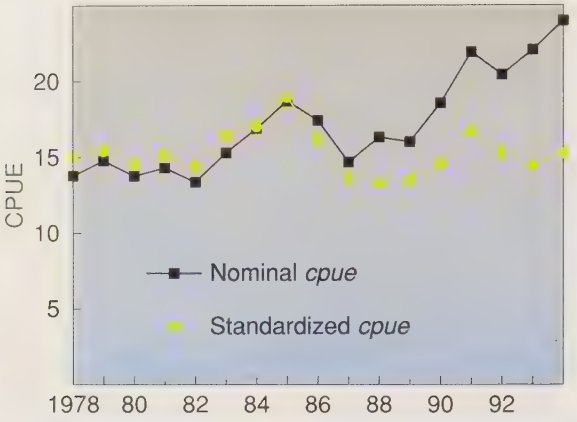

Fig. 3: Nominal and standardized West Coast hake cpue *time-series*

analyses are now being applied to the South Coast resource.

A project on the resources and management of the inshore trawl fishery on the South Coast continued, investigating aspects such as mesh size deployed, rates of discard (although discarding is illegal) and by-catch proportions. The region is known to be an important nursery area for demersal fish species and an estimated 24% of the hake catch is discarded because of its small size (<35 cm total length), suggesting that the permissible 75-mm mesh is inappropriate for hake-directed fishing. Sole discards are low (6%) because trawlers avoid areas of high juvenile abundance.

A two-year experimental longline hake fishery was launched in December 1995. During this exploratory stage, the selectivity patterns observed in the pilot study will continue to be monitored for change, and methods of controlling and monitoring the fishery will be researched. The potential impact of longlining and trawling on the egg production of both the deep- and shallow-water species of hake will be investigated, with monthly sampling of gonads to identify the periods of peak reproductive activity. Hake spawning is also being addressed through histological studies to verify the gonad staging indices commonly used and to determine the frequency of spawning. The latter has important consequences for the expected productivity of the resource, as annual egg production is believed to differ between species, with fish size (age) and by area. Changes in gear selectivity through the introduction of new fishing techniques, such as longlining and handlining, or by shifts in fishing strategy, may therefore have important implications for resource assessment and future management of these stocks.

Virtual Population Analysis (VPA) has been routinely applied to assess the Agulhas sole stock, but there are still conflicting trends in the catch rate and survey biomass time-series. In an earlier study the relative effects of sediment type, depth distribution and hydrography on catch rates were investigated. Details of a new study on the impact of the environment on seasonal and annual variability in catch rates of Agulhas sole are given later. The age determination of Agulhas sole has been problematic in the past because the assumed formation of annual rings has not been validated, but daily ring counts of otoliths of juvenile sole, by a postgraduate student of the University of the Western Cape, have resolved some of these problems. This new knowledge can now be applied to reassess age-length keys and the age structure of sole catches.

Collaboration with Namibia in the field of demersal research has been extended to include Angola, under the auspices of the BENEFIT programme. BENEFIT is funded from a variety of local, regional and international research and development sources. Hake and horse mackerel are two of the designated key species for research in the programme, recognizing their commercial value as well as their large fluctuations in abundance, with socio-economic implications for the region.

The Institute is also closely involved in the SANCOR by-catch research programme, which aims to investigate the species composition and

Fig. 4: A haul of warty oreo-dory (inset) is sorted aboard FRS Africana

distribution of the main by-catch species as well as discard proportions in trawls. The observer programme was restructured at the beginning of 1996, facilitating easier data collection, and several of the biological studies, including those on gurnard *Chelidonichthys capensis* and the sharks *Squalus megalops* and *Mustelus* spp., were completed by year-end. The study into the biology of the skates *Raja wallacei* and *Raja pullopunctata* indicated that although they are both common to the by-catch, their potential for greater utilization is limited because of their low overall abundance, economic value and consumer demand. Four new postgraduate projects on the biology of jacopever *Helicolenus dactylopterus*, ribbonfish *Lepidopus caudatus*, the rattails *Coelorinchus simorhynchus*, *Coelorinchus braueri* and *Malacocephalus laevis*, angelfish *Brama brama* and Cape dory *Zeus faber* were initiated at Rhodes University and the University of the Western Cape at the beginning of 1997. In addition, a doctoral student is investigating the composition and distribution of the teleost component of the by-catch, and the biology, distribution and stock assessment of the monk *Lophius vomerinus*.

Exploratory deep-water trawling recommenced off the South African coast in August 1996 after a prolonged period of inactivity, and a concerted effort is once again being made to find commercially viable deep-water stocks. Two permit-holders have each entered into collaborative ventures with other established fishing companies in an attempt to defray costs, and four companies are now directly involved in the exploratory venture, using a wet-fish boat and a large freezer trawler. The primary target species, orange roughy *Hoplostethus atlanticus*, has proved elusive and very small quantities have been landed to date. However, some good catches of oreo-dory have been made, although these have also been sporadic. The oreo-dory species complex comprises at least five species,

of which two, the warty *Allocyttus verrucosus* and smooth *Pseudocyttus maculatus*, have made up the bulk of the catches. Traces of spikey *Neocyttus rhomboidalis*, oxeye *Oreosoma atlanticum* and rough *Neocyttus* sp. oreo-dory have also been present. Other deep-water species with commercial potential include alfonsino *Beryx splendens* and cardinal *Epigonus telescopus*. Exploratory commercial trawls caught approximately 1 000 tons of deep-water dories in 1996 and indications are that the fishery will expand in 1997.

In March 1997 the Institute contracted a student to investigate aspects of the biology of these target species and provide information for input into stock assessment models. Another, industry-funded, student has developed a model with which to produce baseline biomass estimates for the orange roughy and oreo-dory stocks off the South African coast. As these deep-water species are characterized by slow growth and late maturity, they are particularly vulnerable to overexploitation. Should a deep-water commercial fishery be established, a conservative management approach will be adopted by Sea Fisheries in an attempt to avoid overcapitalization during the early stages and to promote sustainability of the stocks in the long term.

Stock assessments conducted at the International Commission for the Conservation of Atlantic Tunas (ICCAT) indicate that the southern Atlantic albacore (longfin tuna *Thunnus alalunga*) stock has been overexploited since the mid-1980s. As a result, ICCAT implemented an international catch limit of 22 000 tons for albacore in the southern Atlantic Ocean in 1996.

The relationship between albacore in the southern Atlantic and Indian oceans was recently addressed in a co-operative study by South African (including Institute) and Taiwanese fisheries scientists. A better understanding of this relationship is crucial, because the possibility of catches in the South-East Atlantic being supplemented by migration of fish from the Indian Ocean has important implications for albacore stock assessment and management in both oceans. However, the study showed that albacore tagged off south-west Africa undergo no migratory movement towards the east, and distribution patterns of albacore larvae indicate separate spawning areas in the two oceans. The geographic distribution of albacore catches also shows a consistent discontinuity off southern Africa (Fig. 5), apparently resulting from the warm Agulhas Current acting as a thermal barrier to this temperate species.

Albacore from the Atlantic and Indian oceans were also morphometrically and genetically compared, and both methods revealed some significant differences, suggesting marked separation of albacore in the two ocean basins. While these results do not completely eliminate the possibility of some interchange between the Indian and Atlantic oceans at times when the Agulhas Current weakens, they do suggest that this interchange is limited. It therefore appears that albacore in the southern Atlantic and Indian oceans can be considered as separate stocks, which should be assessed and managed accordingly.

Similar questions arose concerning the relationship between yellowtail *Seriola lalandi* occurring west and east of Cape Point during 1996. These were prompted by an application for a permit to catch yellowtail off the North-West Cape using a purse-seine net, on the basis that these fish constitute a separate stock. The Institute therefore studied the morphometric relationships between yellowtail from the two areas, and migration patterns of yellowtail tagged off the West Coast.

Samples of yellowtail were obtained from Struis Bay on the South Coast and off Blinkwater Bay on the West Coast for morphometric comparison. A number of meristic counts and morpho-

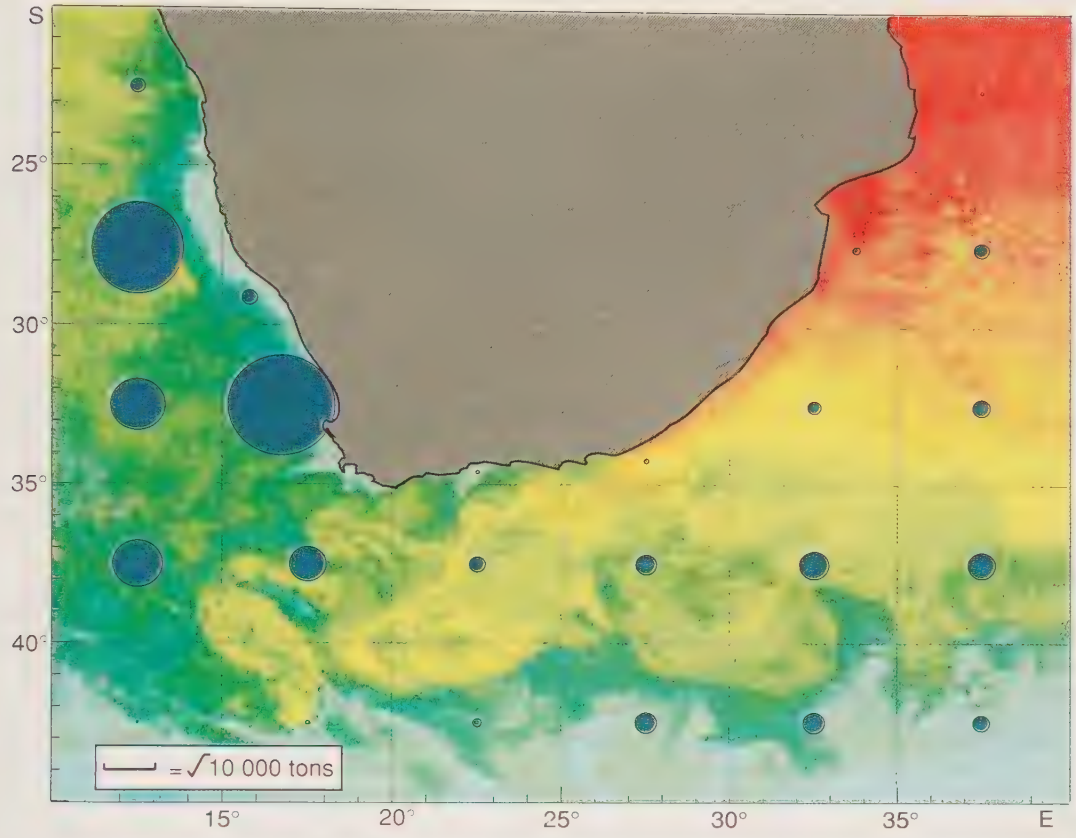

Fig. 5: Composite satellite image of sea surface temperature off southern Africa, showing the Agulhas Current and total albacore catches by South African and Taiwanese fishing vessels, 1985–1992

metric measurements were made on these fish, and statistically compared. Results showed no significant differences, providing no evidence for the existence of different "stocks" or ecotypes of yellowtail. Of a total of 1 171 yellowtail tagged off Blinkwater Bay, 37 have since been recaptured. The long maximum time at liberty (334 days to date) and the excellent condition of tags and fish returned after this extended period suggest good retention of tags.

The recapture data revealed a steady and progressive southward movement of the West Coast yellowtail shoals across False Bay and as far as Struis Bay, in response to changes in wind patterns. Together with the morphometric results, this migration pattern indicates that yellowtail off the Cape west and south-west coasts constitute a single stock, that should be managed as such throughout South Africa.

The Institute has also been conducting research on the dusky kob *Argyrosomus japonicus*, which occurs on the east coast of South Africa and is abundant between Cape Agulhas and the Moçambique border. Juveniles (<100 cm) are found in estuaries and the surf-zone, and tagging studies have shown that they are not migratory. The adults frequent both these habitats, but are found predominantly beyond the surf-zone to depths of about 50 m. A large portion migrate to KwaZulu-Natal to spawn in spring, when they are targeted by ski-boat fishermen. A recent stock assessment, based on per

recruit analyses, indicates that this species has been severely overexploited and that the spawner biomass has been reduced to 1.4–7% of its pristine condition. Contrary to expectation, the stock depletion seems to be caused by fishing pressure exerted by estuarine and rock-and-surf anglers on juvenile fish, rather than the activities of ski-boat fishermen.

Other projects currently conducted by the Institute include one on the life history and population dynamics of snoek *Thyrsites atun* and another on the impact of inshore trawling on linefish stocks. Data collection for both projects was initiated in 1994 and will continue until the end of 1997, before being analysed and published.

Squid

During 1996, stock assessment for the chokka squid *Loligo vulgaris reynaudii* resource was developed further at the Institute. This was aimed at providing more efficient advice to management in response to increased pressure on the resource in the form of new applications, new permit conditions, creeping effort increases and the increasing role of the "recreational" fishery. A Bayesian assessment of the trends in four indices of stock abundance showed a pronounced decline in squid abundance from 1971 to 1994, although the results from recent demersal surveys suggest an increase in abundance. The reasons for this apparent contradiction are currently being investigated. In addition, a random survey was designed in consultation with the University of Cape Town to assess catch and effort by the recreational chokka fishery.

Hydroacoustic observations are also being made in an effort to quantify the size of the stock directly. Cage experiments, described in more detail later, were used to collect data on squid target strength, and revealed that the shape and behaviour of chokka spawning concentrations vary considerably. This finding needs to be thoroughly investigated before hydroacoustic methods of stock assessment, in conjunction with bottom-trawl surveying, can be used routinely in the field.

Age and growth research focused on validation, development of increment visualization techniques, and daily age estimates. Aspects of the physiological mechanisms of squid statolith formation have been investigated, including the daily cycles in calcium and magnesium abundance in statocyst endolymph, and the isolation and sequencing of some of the protein components of statoliths. An understanding of the statolith deposition process may allow daily increments to be correctly identified, with no need for validation.

Research on squid maturity yielded a fecundity estimate of 8 000–16 000 eggs per female, depending on various factors such as the rates, variation and periodicity of egg production, and the size of the animal. During the reproductive season the ovaries of mature females contain post-ovulatory corpus luteum alongside oocytes in various stages of development, suggesting that the species is a serial spawner capable of laying multiple batches of eggs throughout its life.

The next step in this research is aimed at determining the timing and intensity of spawning on a population scale. The characteristics of various ages of post-ovulatory follicles are being defined so that they can be used as indicators of spawning frequency, and the extent of follicular atresia may in future be used as an index of the population's reproductive potential. Such information will be used in modelling the optimal duration and timing of the closed season. Preliminary results obtained from modelling the dynamics of squid biomass on the spawning grounds have shown that the closed season has played a major role in the conservation of chokka.

Environmental research focused on the development of the Environmentally Driven Predictive Capability (EDPC) for the chokka jig fishery,

Fig. 6: Squid tagging and oxytetracycline injection for migration and age validation studies

aimed at enabling managers and the industry to predict squid abundance before the main season begins. Research was also carried out to investigate environmental impacts on the squid life cycle.

Abalone

The fishery independent abalone survey (FIAS), designed to provide an annual index of abalone *Haliotis midae* biomass, remains a large commitment for Institute staff, especially during the first half of the year when sea conditions are suitable for diving. A few more years' data are required for interpretation of trends, but preliminary indications confirm the depressed state of the resource in the Mudge Point/Hawston area.

A co-operative research programme with the University of Cape Town has been initiated to investigate the disappearance of sea urchins *Parechinus angulosus* from sites at Betty's Bay and Mudge Point, probably caused by an influx of the predatory West Coast rock lobster *Jasus lalandii*. The unusually large number of rock lobster in the kelp forests there is also associated with a marked decline in the abundance of other invertebrates, such as turban shells *Turbo cidaris* and various whelk species. In contrast, the continued presence of sea urchins at Danger Point has been confirmed by diving surveys, which will be an ongoing means of monitoring the abundance of sea urchins, abalone, rock lobster and other key kelp forest invertebrates.

Recreational abalone landings, which have fluctuated in the range 350–500 tons over the past five years, were estimated at 423 tons in 1995/96. The number of permits sold declined from 34 000 to 33 000. For the first time since recommendations were made to curtail the expanding recreational fishery, a three-month reduction of the recreational diving season

was approved for the 1996/97 season. This, combined with the apparently stabilizing trend in recreational landings, is a positive development for the resource, which is under severe pressure at present.

Poaching remains a major threat to the sustainability of future abalone harvests, and was the principal motivation for the 50% reduction of the *TAC* in the Mudge Point/Hawston area for the 1996/97 season. This area has been the centre of poaching activities for a number of years, and research data are now showing clear signs of such pressure. Unfortunately, poaching effort is now moving farther afield into more remote areas such as Celt Bay and Buffeljags, and samples from officially confiscated hauls contain a high proportion of undersize animals. Unless poaching is effectively curtailed, drastic reductions in the *TAC* can be anticipated throughout the range of the fishery.

Growth rates of West Coast rock lobster *Jasus lalandii* measured by the Institute during the 1995/96 season showed a slight increase over those of recent years, a trend confirmed by preliminary analysis of tag returns for the 1996/97 season as well as reports from the fishing industry that landed lobsters were in good condition and had a size-distribution with a larger than usual mode. Growth rates are currently determined from post-moult tagged lobsters returned during the fishing season, which commences immediately after the male moulting period. Stock assessments are therefore compromised by the need to rely on growth trends over previous seasons, excluding the most recent one. However, significant progress has been made in the development of a predictive index of growth, based on the biochemical composition of the digestive gland. Once refined, this technique may be used to predict growth during the subsequent moult for input in the assessment procedure.

The stock assessment procedure is undergoing a major revision at present, the aim being to replace the size-based modelling approach, which involves considerable debate on both input and methodology, with an automated Operational Management Procedure (OMP). This methodology will allow *TAC*s to be set according to the existing indicators of resource status, such as growth, commercial *cpue* and trends from the Fishery Independent Monitoring Survey (FIMS), which can be unambiguously defined and derived according to standardized analytical procedures. Some aspects of the OMP have yet to be endorsed by the industry and tests of sensitivity and robustness completed, but the new methodology is being debated with representatives of the resource users.

The 1996/97 fishing season was disrupted by a severe nearshore oxygen depletion event in the Elands Bay area, caused by a large red tide. The event resulted in the largest "walkouts" of rock lobster ever recorded, and by mid-May more than 2 000 tons of lobsters had been stranded along the West Coast between Dwarskersbos and Lambert's Bay (Fig. 7). Although some of the beached lobsters were saved through the co-operative efforts of Sea Fisheries, the industry, the police and the Defence Force, large quantities were removed by the public or died on the shore. Subsequent diving surveys have indicated dramatic reductions in the number of lobsters in the Elands Bay region.

In response to continued requests by the Institute, permission was granted in December 1996 to conduct lobster research east of Cape Hangklip. A stratified ringnet and trap survey of the population in this area is currently under way. Initial results indicate a substantial population in waters between 5 and 100 m depth, as far east as Hermanus. Earlier hypotheses were that this was a result of adult migration from the West Coast, but as large numbers of recruits were observed, investigations on larval settlement in the region will soon be initiated.

Fig. 7: Low-oxygen conditions resulting from an extensive red tide in the Elands Bay area caused the largest mass mortality of rock lobster ever recorded in South Africa

Research on South Coast rock lobster *Palinurus gilchristi* is aimed at providing biological and fisheries information for stock assesssment purposes. An observer programme was initiated in 1994 to provide size composition data for length- and age-based models that are being developed to replace the surplus production model currently used for stock assessments.

The ongoing tagging programme, in which 5 000 lobsters are tagged per year, has yielded reliable estimates of growth, and recapture rate is used to estimate the proportion that can be harvested. However, much of the information is lost because of tag-induced mortality, tag-shedding and low reported rates of tag-recapture. Institute personnel now visit returning vessels on a regular basis to improve reporting rates, and a lucky draw cash prize will in future be offered as an incentive. A double-tagging experiment to investigate tag-shedding is presently under way in St Francis Bay.

Numerical analyses of the resource, based on commercial catch rates between 1977 and 1996, have indicated an annual decline of about 2% in resource biomass. Particularly low catch rates for the early part of the 1996/97 season have raised concerns within the industry. The view that an escalation in effort in recent years is distorting commercial catch rate data because of competition between different sets of gear (and consequently a decline in the capturing efficiency of traps) is currently being investigated. A depletion experiment to determine fishing down and recovery rates at different levels of effort is in its pilot phase.

Marked declines in trap catches after the first three years of an experiment to investigate the viability of a commercial fishery for Natal deep-water rock lobster *Palinurus delagoae* suggest limited potential. Annual relative abundance indices over the three-year period declined by 40% in the northern region, 47% in the central

region and 84% in the southern region of Kwazulu-Natal. It appears that at depths of 200 –400 m there are few hard substrata patches where the lobsters occur in sufficiently high numbers to justify commercial fishing. A large stretch of the coastline falls within a marine reserve and cannot be surveyed, whereas other stretches consist of a muddy sea bottom on which *P. delagoae* is scarce. Strong currents continue to cause delays by submerging surface gear for extended periods. The experiment continues in 1997, and permits have been granted to two vessels that will be accompanied by observers.

More than four years of research at Saldanha Bay have increased understanding about mariculture of the red seaweed *Gracilaria gracilis*. Growth of *Gracilaria* on horizontal, suspended rope or netting lines in Small Bay, Saldanha, was optimized by keeping the plants close to the surface (usually about 20 cm depth) where water motion caused by wind chop results in better nutrient uptake by the seaweed. An average growth rate of 5% per day (mass increase) was obtained over the course of the four-year study. This rate takes into account periods of one to three months in summer when the warm surface water has a very low nutrient content and growth may drop to below 1% per day. The study gave a projected yield of about 36 tons (dry mass) of *Gracilaria* per hectare, but proper commercial-scale mariculture is needed to confirm this estimate. The Institute continued its involvement in collaborative studies with the University of the Western Cape on site selection for *Gracilaria* mariculture in Saldanha and St Helena Bays, and with the University of Cape Town on ecophysiology and strain selection of the local species.

The experiment to assess the effects of kelp *Ecklonia maxima* harvesting at Danger Point, Gans Bay, came to an end this year. Harvesting of kelp plants taller than 0.5 m had no effect on the species diversity or biomass of other benthic flora and fauna. However, kelp recruitment from sporelings settling after harvesting was slow and sporadic during 1993 and 1994, although it improved during 1995 and 1996. The main factor preventing good kelp recruitment appeared to be the large numbers of grazing invertebrates, such as abalone, sea urchins and turban shells, present in the area. Owing to such slow recovery, large-scale harvesting of whole plants is not recommended, but current research is investigating the effect of harvesting the fronds only. Initial results show that cutting the fronds 30 cm from their origin on the primary blade has the least effect on the kelp plants and maximizes regrowth. Further studies are examining the effects of different harvesting intervals.

A survey to map and quantify the biomass of South African kelp resources was started in 1995, and the fieldwork was completed in 1996. Aerial photographs (either colour or infra-red) were taken of the coast between the Orange River and the Cape Peninsula, and will complement existing records for the area between Cape Agulhas and the Peninsula. Beds between the Orange River and Brand se Baai (north of Doring Bay) and between Cape Columbine and North Head, Saldanha, have been surveyed and maps are in preparation. Diving surveys have been conducted in these areas as well as at Kleinsee, Doring Bay, Lambert's Bay, Elands Bay and near Saldanha. All kelp within quadrats in the inshore, mid- and offshore zones is cut and weighed, so that biomass values can be integrated with the maps. These surveys reveal the gradual replacement inshore of *Ecklonia maxima* by *Laminaria pallida* north of Lambert's Bay.

A kelp-harvesting experiment was started in May 1995 at Jacobs Bay near Saldanha, in which all kelps with stipes longer than 50 cm were cut out of a 20 x 20 m area. This area, like most of the West Coast north of Cape Point, has few benthic grazers, and kelp recruitment and re-growth has been satisfactory. Monitoring will continue until

Fig. 8: A diver tags a kelp plant as part of an experiment to assess the effects of harvesting

new plants form a surface canopy and a population structure similar to the adjacent control is established.

Studies of the biology of several species of carrageenan-producing red seaweeds from the Western Cape, including *Gigartina polycarpa* and *Sarcothalia stiriata*, continued during the year. These focused on culture studies aimed at determining light and temperature tolerances for growth and cultivation. Both species were found to be light saturated at low irradiances (about 30 $\mu mol \cdot m^{-2} \cdot s^{-1}$). This appears to be an adaptation to maximize growth after spore germination, because although the intertidal habitat is exposed to high light intensities, the sub-canopy microhabitat in which the sporelings grow is characterized by low light. The growth rates of both species peak at temperatures of 10–15°C, and neither survives temperatures greater than 20°C for extended periods. These results improve understanding of natural population dynamics, and will be essential for cultivation experiments planned for the forthcoming year.

HIGHLIGHTS OF SUPPORTING RESEARCH

Investigating the formation of red tides

Harmful algal blooms, usually characterized by the proliferation and occasional dominance of a particular species of toxic or otherwise harmful alga, are a regular feature of the South African coast, particularly the West Coast. In many instances the blooms discolour the water as red tides, which may impact both commercial and recreational interests through faunal mortalities caused by algal toxins, human illness resulting from contaminated shellfish, or the indirect effects of biomass accumulation, such as anoxia.

Red tides are particularly common north of St Helena Bay during late summer and autumn. The composition of the bloom is similar each year and is normally dominated by species of the migratory dinoflagellates *Ceratium* and *Prorocentrum*. Also present are the toxic species *Alexandrium catenella* and *Dinophysis acuminata*, responsible for Paralytic and Diarrhetic Shellfish Poisoning respectively. Recent studies by the Institute have explored the coupling of the physical environment with the biological behaviour and physiological adaptation of dinoflagellate blooms, in an attempt to understand how physical and biological processes interact to promote bloom development and maintenance.

Transect studies conducted at Lambert's Bay during late summer revealed that in the highly stratified waters offshore the bloom had accumulated in a narrow subsurface layer at the thermocline (Fig. 9a), where the dinoflagellates could balance their requirements for both light and nutrients. Inshore, the bloom was displaced from the coast by a narrow belt of upwelled water, and had accumulated as a high-biomass surface bloom in the frontal region where mixed and stratified waters met. Here the population underwent diel vertical migration as a means of regulating nutrient uptake and photosynthesis. These observations demonstrate the ability of dinoflagellates to adapt their migratory behaviour to *in situ* conditions.

Vertical profiles of light, biomass, production and productivity per unit chlorophyll (P:B) provided further insight into the physiology and vertical positioning of the bloom (Fig. 9b). Offshore, where the dinoflagellate population was subsurface and exposed to light intensities less than 0.5% of surface irradiance, rates of production were low. This, together with the low P:B ratios, suggests that these large blooms are either maintained by other types of nutrition, such as phagotrophy or osmotrophy, or have grazer-resistant properties.

The highest rates of production were observed in the frontal region, and it is surface blooms such as these that are responsible for coastal red tide when advected onshore. Time-series data at an inshore station have revealed that relaxation or reversal of upwelling winds is typically followed by rapid onshore movement of the upwelling front and the accumulation of the bloom inshore (Fig. 9c). The bloom remains associated with water of a narrow temperature range and appears to be displaced with the advection of even warmer water.

This understanding of the physical processes leading to red tides not only enables the Institute to increase the efficiency of its harmful algal bloom monitoring programme, but may in future also be used to predict red tides, leading to improved management of the resources of the southern Benguela.

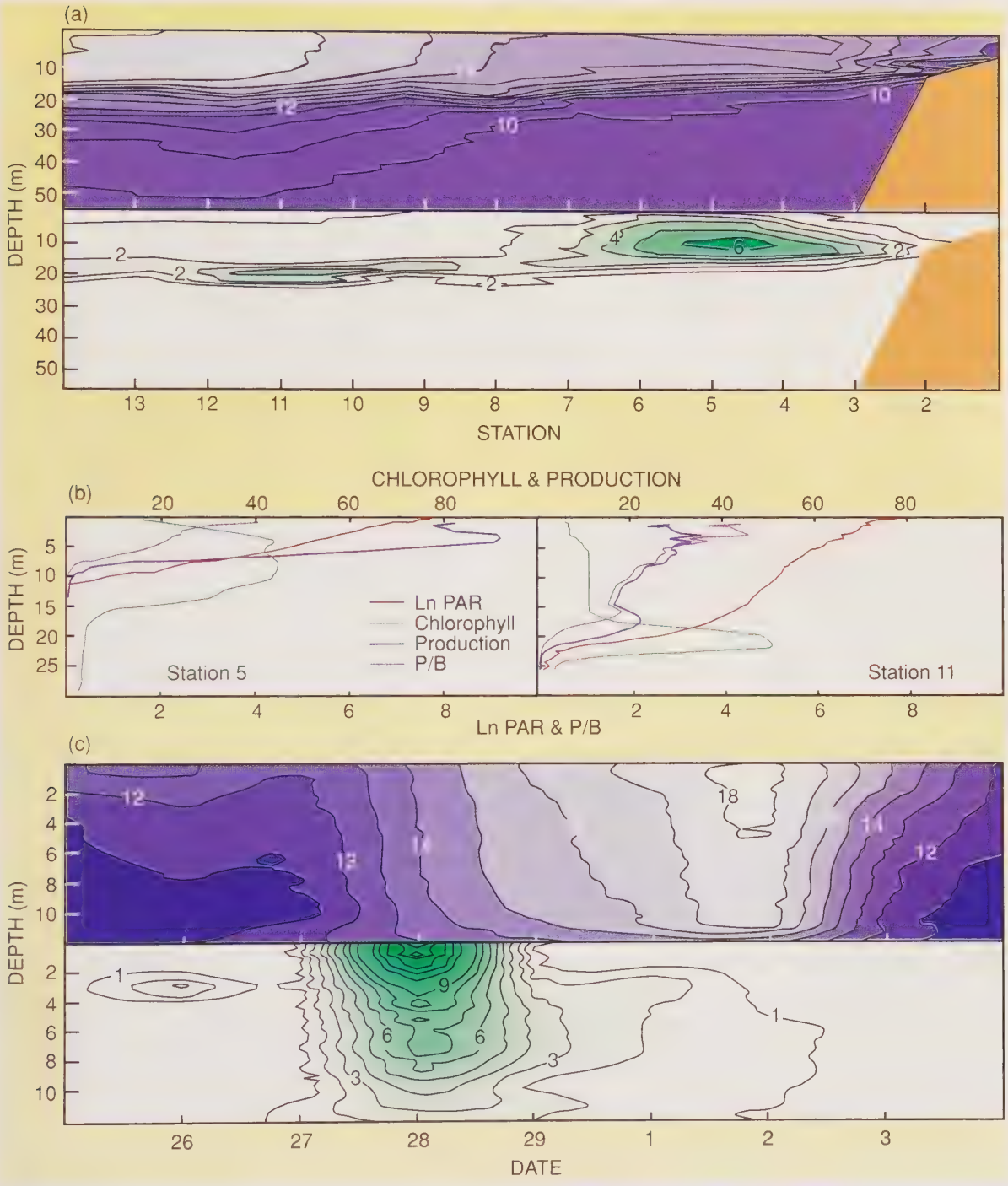

Fig. 9: *Profiles of (a) a 28-mile transect off Lambert's Bay on 16 February 1996, showing temperature (above) and* in situ *fluorescence (below), (b) light* (PAR – *photosynthetically active irradiance), chlorophyll* a, *production and P:B for two transect stations, and (c) a time-series of temperature and* in situ *fluorescence, 25 February-4 March*

Recent evidence suggests that upwelling-favourable winds in eastern boundary current ecosystems have increased over the past five decades. Although this has unknown consequences for pelagic foodwebs, intensified upwelling is hypothesized to have altered the abundance and species composition of zooplankton assemblages, which form an important food source for many of the fish species supporting large fisheries. The Institute therefore initiated a project to re-analyse data from zooplankton collections made during the past five decades in the Cape Columbine – St Helena Bay area of the southern Benguela upwelling system, the centre of recruitment for the anchovy and sardine fishery on the West Coast.

A time-series of the abundance of planktonic crustaceans, the most important zooplankters in the diet of anchovy and sardine, revealed a significant increase over the past 45 years (Fig. 10b). This trend may reflect a biological response to intensified coastal upwelling (Fig. 10a) and the resulting enhanced primary and secondary production, as well as increased advection and retention of planktonic biota within the study area.

Alternatively, the increasing trend in crustacean zooplankton abundance may be caused by a long-term reduction in predation pressure by planktivorous pelagic fish, as the decline in pelagic catches from 1960 onwards (Fig. 10c) may reflect a decrease in stock size. This decline, in turn, may result from increased predation by top predators such as snoek *Thyrsites atun* (Fig. 10d) or the Cape fur seal *Arctocephalus pusillus pusillus*, the population of which has grown rapidly in recent decades as it recovers from overexploitation.

The relative importance of such control mechanisms cannot be assessed at present, and in studies elsewhere, climate alone has been suggested

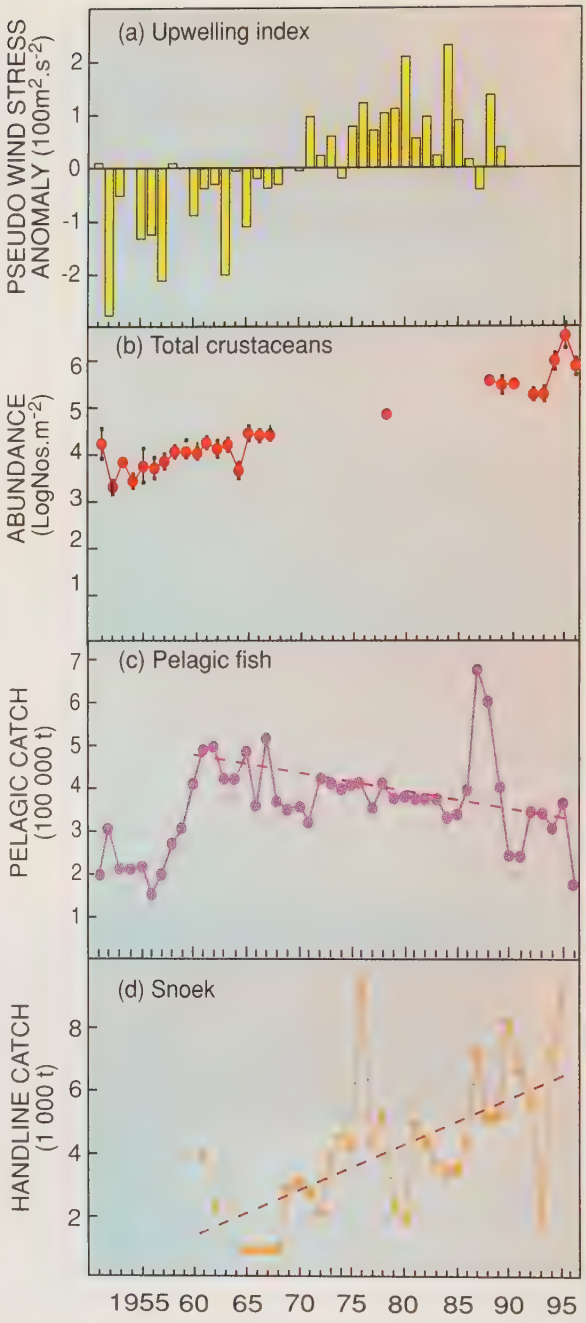

Fig. 10: Time-series of (a) upwelling-favourable winds, (b) the abundance of crustacean zooplankters, (c) annual tonnages of pelagic fish landed by the South African pelagic industry and (d) annual catches of snoek made by handline off South Africa

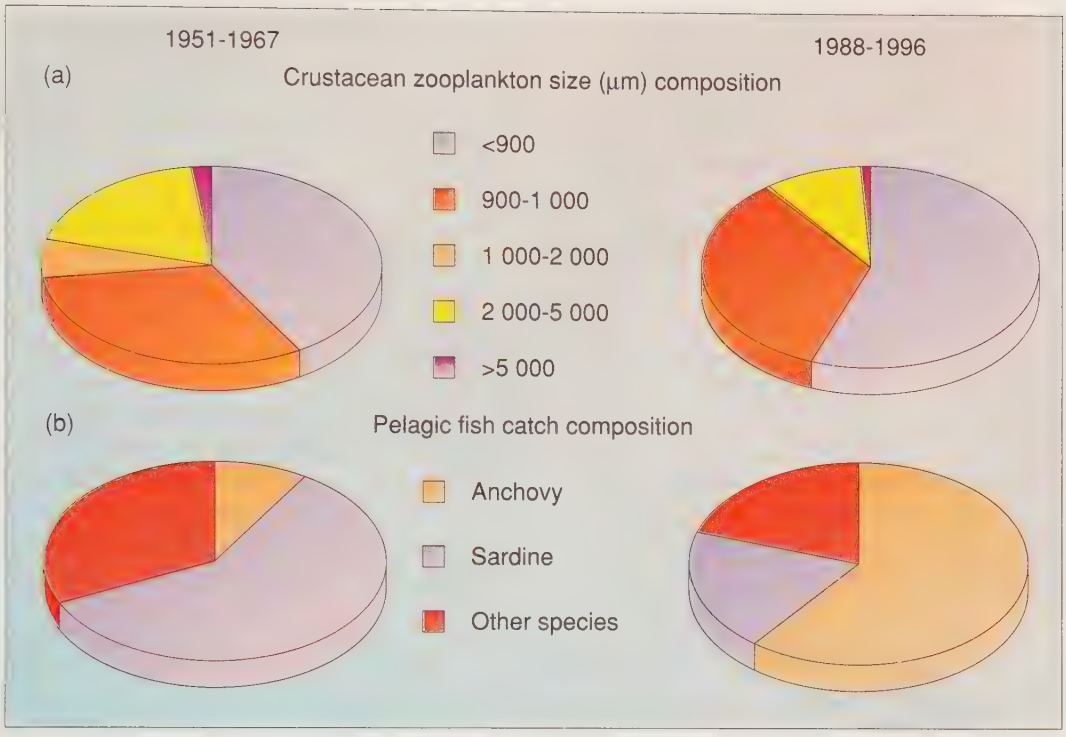

Fig. 11: Average percentage composition of (a) crustacean zooplankton size fractions and (b) pelagic fish catches, 1951-1967 and 1988-1996

as the causative mechanism for long-term changes in zooplankton assemblages. However, in the southern Benguela a significant shift in the size structure of the crustacean zooplankton community over time (Fig. 11a) coincided with an altered regime in sardine and anchovy abundance (Fig. 11b). The period 1951–1967, when sardine was the dominant species, was characterized by a lower proportion of <900 µm zooplankton in the samples than 1988–1996, when anchovy were dominant. This may be a reflection of the known preference of sardine for small food particles. Conversely, the proportion of >1 000 µm zooplankton, the preferred food of anchovy, was reduced from 27% during the years 1951–1967 to 11% during anchovy dominance in 1988–1996.

The elevated levels of zooplankton abundance observed to date in the St Helena Bay area should support larger stocks of planktivorous pelagic fish than in previous decades. However, because of the complexity of the ecosystem, any mechanisms responsible for long-term trends in zooplankton and other trophic levels are likely to be considerably more complicated than simple trophic interactions. The construction of foodweb models capable of reproducing these trends is therefore a major challenge to scientists at the Institute.

Studying the vertical [illegible] copepods

As copepods are an important food source for pelagic fish, particularly anchovy, sardine and horse mackerel, aspects of copepod life history and feeding ecology are investigated by the Institute to increase understanding of fish

foraging behaviour and foodweb dynamics. The ability of copepods to migrate large distances through the water column each day may be an adaptation to avoid predators, locate suitable patches of food, spawn in areas favourable for the newly hatched nauplii, or use subsurface currents to migrate horizontally. Typically, diel vertical migration entails concentrating near the surface at night, where food is generally more abundant and the darkness provides protection from visual predators, then moving deeper during the day, where food is scarce but light levels are low.

The diel vertical migratory behaviour of *Calanus agulhensis*, the dominant large copepod on the Agulhas Bank, was investigated using a rectangular midwater trawl (RMT) with six nets that could be triggered at different depths. Under conditions of abundant food on the Agulhas Bank, *Calanus* clearly undertook diel vertical migration (Fig. 12a), ascending to the food-rich upper layers at sunset and descending before sunrise. By mid-morning the entire population, except for the smallest copepodite stages (C1s), had returned to deeper water. As in many other copepod species, older stages were found to migrate deeper than the younger stages, a phenomenon known as ontogenetic layering.

When food was less abundant, *Calanus* spent more time in the upper water column, the copepods either remaining in the relatively food-rich layer for longer or descending more slowly, so that by mid-morning the population had not yet completed its descent (Figs. 12b, c). Support for

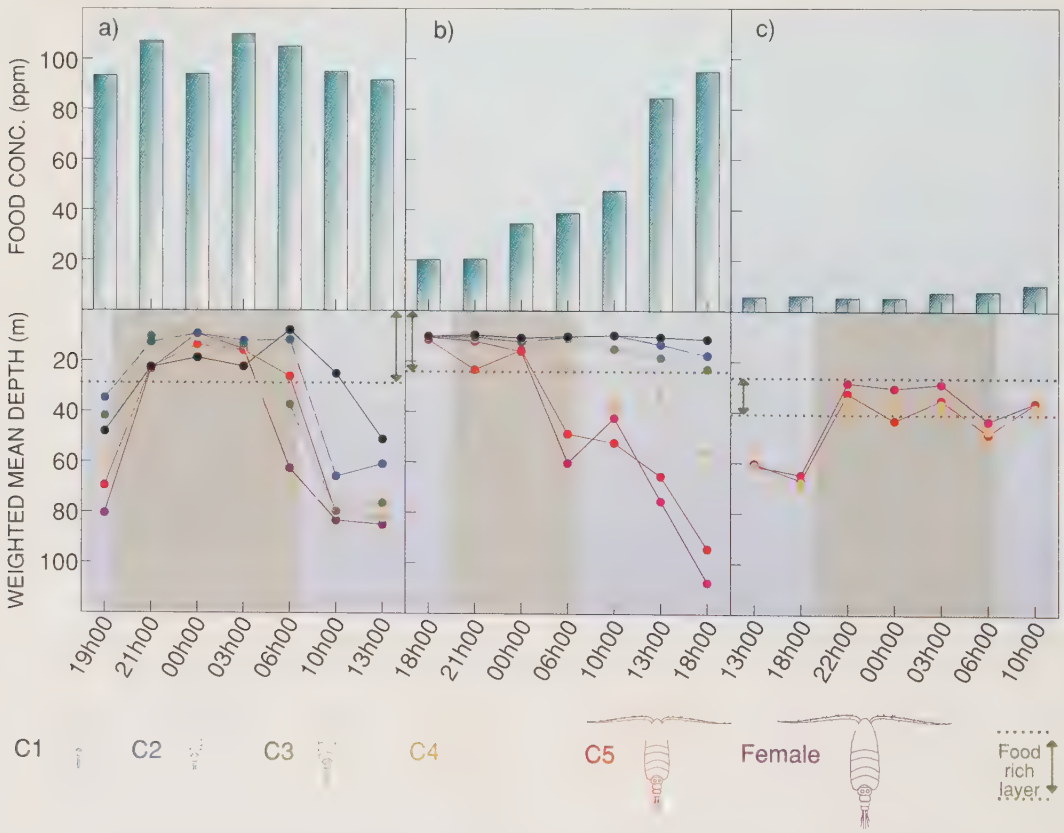

Fig. 12: Vertical migration of Calanus agulhensis *under different conditions of food availability*

this finding was the positive relationship between food abundance and an index of the magnitude of diel vertical migration. If food remained limiting, the copepods ascended early or remained near the surface during daylight.

These results suggest that the vertical migratory behaviour of *Calanus* is directly related to food abundance, the copepods attempting to obtain a minimum food ration before descending to the relative safety of deeper water. The reward of this minimum ration, presumably to maximize growth in juveniles and egg production in females, must therefore outweigh the higher risk of predation near the surface.

Future research will likely include more regular sampling intervals close to sunset and sunrise to determine the timing and rate of ascent and descent more accurately. In addition, simultaneous measurements of the abundance and vertical movements of planktivorous fish would clarify how *Calanus* modifies its behaviour in response to predation.

[illegible]

Since 1993, when the Institute initiated the Sardine and Anchovy Recruitment Programme (SARP), considerable progress has been made in understanding pelagic fish recruitment. Although factors such as the survival of eggs and larvae and the transport of larvae to the food-rich nursery grounds are partially responsible for the large annual fluctuations in anchovy recruitment, data from the first two years of SARP suggest that successful spawning may be the key.

Anchovy are serial spawners which broadcast their eggs in batches at 10-day intervals between September and February each year on the western Agulhas Bank, their principal spawning ground. Such prolonged spawning is an energetically expensive reproductive strategy requiring a constant food supply, mainly in the form of copepods. Acoustic surveys have located highest densities of anchovy spawners in water between 16 and 19°C, where copepods are also most abundant. The area of 16-19°C water can therefore be considered as the size of the optimal spawning habitat for anchovy, which is also significantly related to the number of anchovy eggs.

The research has shown that, in future, it may be feasible to use satellite thermal imagery to measure the area of 16-19°C water on the western Agulhas Bank throughout the anchovy spawning season, providing an estimate of the total number of eggs spawned without the need for costly ship-based sampling.

[illegible]

A new sampling technique for assessing the abundance and distribution of pelagic fish eggs is currently being evaluated by scientists at the Institute. The Continuous, Underway Fish Egg Sampler (CUFES) was recently developed in the United States to sample the eggs of anchovy and sardine, so that spawning stock size can be estimated using the Daily Egg Production Method (DEPM). The developer of CUFES, Dr Dave Checkley from the Scripps Institution of Oceanography in California, visited South Africa during September 1996, and used CUFES to examine the spatial distribution of sardine eggs over the western Agulhas Bank during a survey aboard the FRS *Algoa*.

The CUFES system consists of a submersible pump, a concentrating device and a sample collector. Seawater is pumped from a depth of 3 m at 500 $\ell \cdot min^{-1}$ into the concentrator, which filters the water and retains the fish eggs and other plankton particles in a reduced fraction of the pump flow. Samples are then collected from this concentrated flow by the sample collector. CUFES can be run continuously as the ship steams or while it is on station, and unlike conventional net samplers, can continue operating

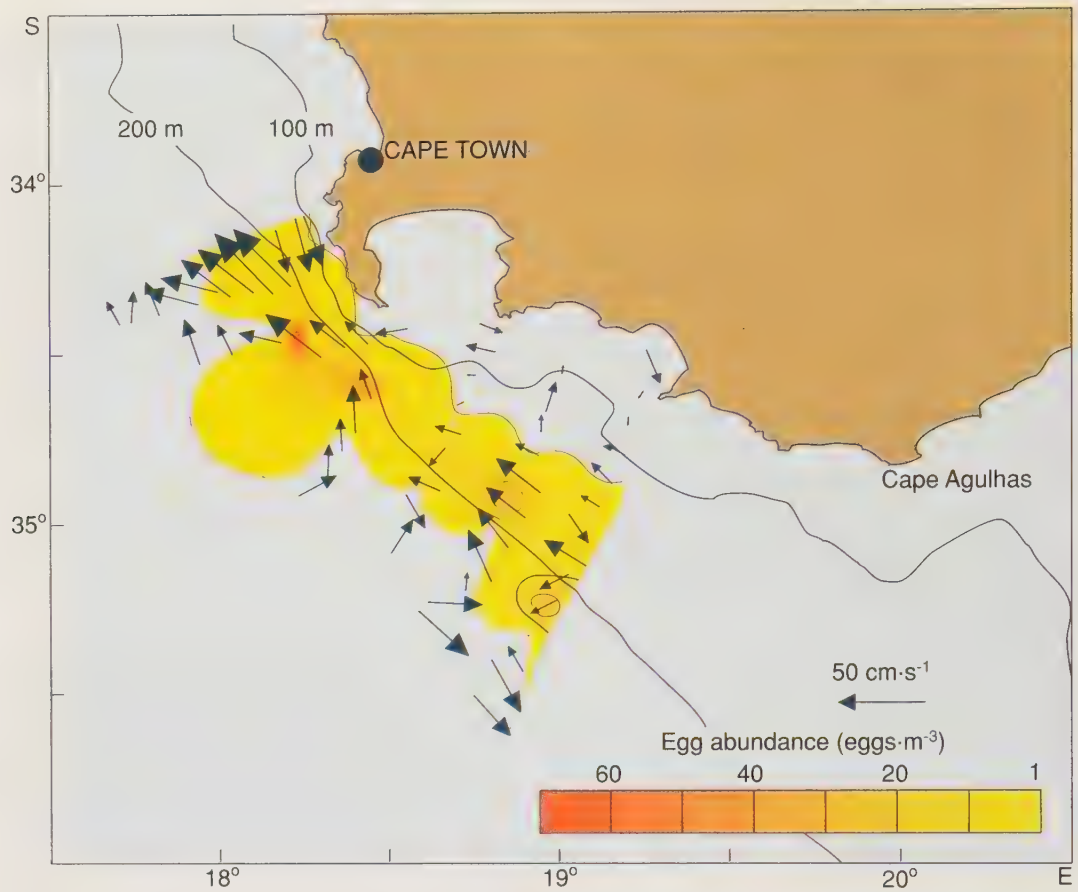

Fig. 13: Sardine egg distribution and subsurface currents (32 m) observed during the CUFES survey

in high winds and heavy seas. Samples are examined on board and fish eggs counted immediately after collection, providing real-time information about egg abundance and distribution. Such information allows for adaptive sampling, whereby the ship's course can be altered to sample areas of high egg abundance more intensively. Previously, eggs were collected at discrete stations in the survey area and samples were analysed ashore, precluding adaptive sampling and being more labour intensive.

Trials conducted during the Agulhas Bank survey showed that volumetric estimates of sardine eggs from on-station CUFES samples were strongly correlated with those from vertically hauled CalVET net tows from 70 m depth, indicating that fish eggs are indeed quantitatively sampled by the system.

Continuous sampling by CUFES also ensured that a map (Fig. 13) of sardine egg distribution over the western Agulhas Bank had much higher resolution than could be generated from CalVET net data. Sardine eggs were found in a narrow band parallel to the coast and extending from 10–30 nautical miles offshore to the shelf edge, the highest egg densities being associated with the strong northwest-flowing jet current detected by the acoustic Doppler current profiler (ADCP). In addition, because of the

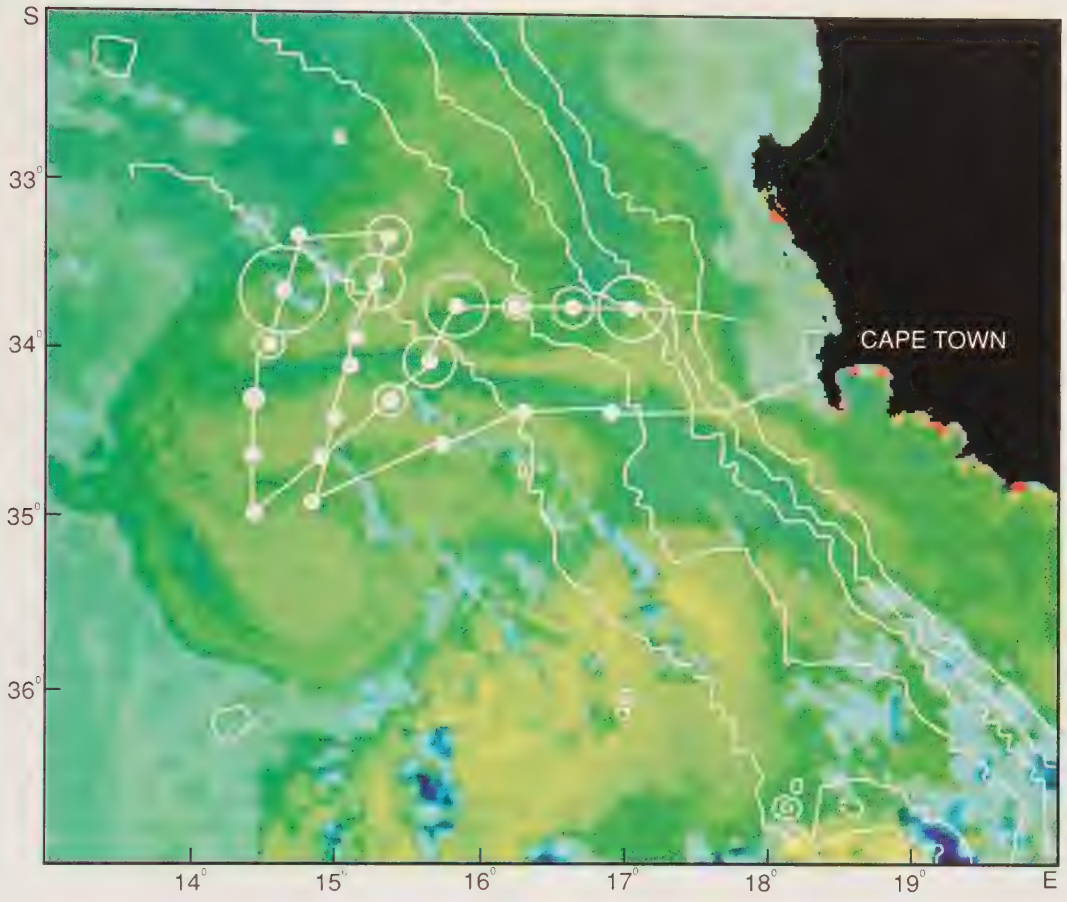

Fig. 14: A composite satellite image of the Agulhas eddy on 19 December 1996 with the cruise track superimposed and the relative abundance of pelagic fish larvae represented by circles around each station

patchy spatial distribution of sardine eggs, continuous sampling by CUFES provided a more precise estimate of average sardine egg abundance than did the CalVET data, reducing the coefficient of variation associated with the mean by some 15%.

CUFES has proved to be particularly suitable for assessing the abundance and distribution of highly aggregated distributions of fish eggs, such as those of sardine. As a result, it will be used by the Institute as part of the DEPM of assessing the spawning stock of sardine during the November 1997 spawner biomass survey.

The warm Agulhas Current flows southwards along the east coast of the African continent, following the topography of the shelf edge. At the southernmost tip of the continent it leaves the shelf edge at the Agulhas Bank and turns back on itself in a loop known as the Agulhas retroflection. Periodically, this loop of warm water pinches off from the main stream of the current and moves into the South Atlantic as an eddy. In its passage across the Cape Basin the eddy may interact with cool filaments from the

Benguela upwelling system on the West Coast, the productive nursery area for the commercially important pelagic fish.

During December 1996, Institute scientists observed such an eddy on satellite images, which showed it moving northwestwards along the western edge of the Agulhas Bank and up the West Coast. This suggested that the eddy had drawn water from the Agulhas Bank, and that it had been replaced by Agulhas Current water. The warm influx across the Bank introduced some tropical fish species, such as wahoo *Acanthocybium solandri* and marlin *Makaira* sp., to the waters of the South and West coasts.

Although the sequence of events appeared clear on the satellite images, some important assumptions could not be confirmed without sampling, and an opportunistic cruise was therefore organized to survey the eddy and the water drawn from the West Coast and Agulhas Bank (Fig. 14). Hydrographic measurements through the water column and subsequent examination of satellite altimeter data confirmed the presence of an Agulhas eddy and its interaction with water from the West Coast upwelling front and the Agulhas Bank.

This evidence was supported by a preliminary analysis of plankton net collections, which revealed a low zooplankton biomass at stations near the eddy core, representing Agulhas Current water, compared to those in the filament where the zooplankton community comprised both Agulhas Bank and West Coast species.

Anchovy and sardine eggs and larvae were also present in the filament samples. It has long been postulated that Agulhas eddies might remove fish eggs and larvae from the Benguela upwelling system, contributing to poor recruitment in some years. The results of this cruise indicate that such eddies can indeed remove spawning products from the system, with negative consequences for the pelagic fishing industry.

Modelling the transport of pelagic fish eggs and larvae

Pelagic fish rely on currents to transport eggs and larvae from spawning areas to suitable nursery areas where they can continue to develop. However, some eggs and larvae may be transported offshore into areas unfavourable for survival and development, contributing to interannual variability in the number of fish recruiting to the fishery.

The Institute recently conducted a modelling exercise to improve understanding of such variability. Current data for the period 1989–1993 from ship-borne acoustic Doppler current profilers (ADCPs) were subjected to random perturbations to simulate small-scale diffusion as well as larger-scale events such as filaments and eddies. A reduced frequency of south-easterly winds off South Africa during the *El Niño* period of 1990–1993 was used as an example of changes in advective processes that might occur with climate change. Transport of anchovy younger than six months (the age of recruitment to the fishery) was modelled under a number of possible advection scenarios.

Enhanced westward flow was predicted to move anchovy eggs and larvae into the region of the jet current, which would result in increased recruitment to the fishery on the West Coast. However, the model showed that if both westward and northward advection were enhanced, offshore advection of eggs and larvae into unproductive waters offshore would be more likely, precluding the formation of strong year-classes. In contrast, reduced westward and northward advection would lead to a year-class strength of more than double that of the baseline and enhanced advection scenarios, as fewer eggs and larvae would be lost to offshore advection and more recruits would accumulate in bays and inshore areas.

Distributions of anchovy spawners in the years 1986–1992 were also modelled using a tuned

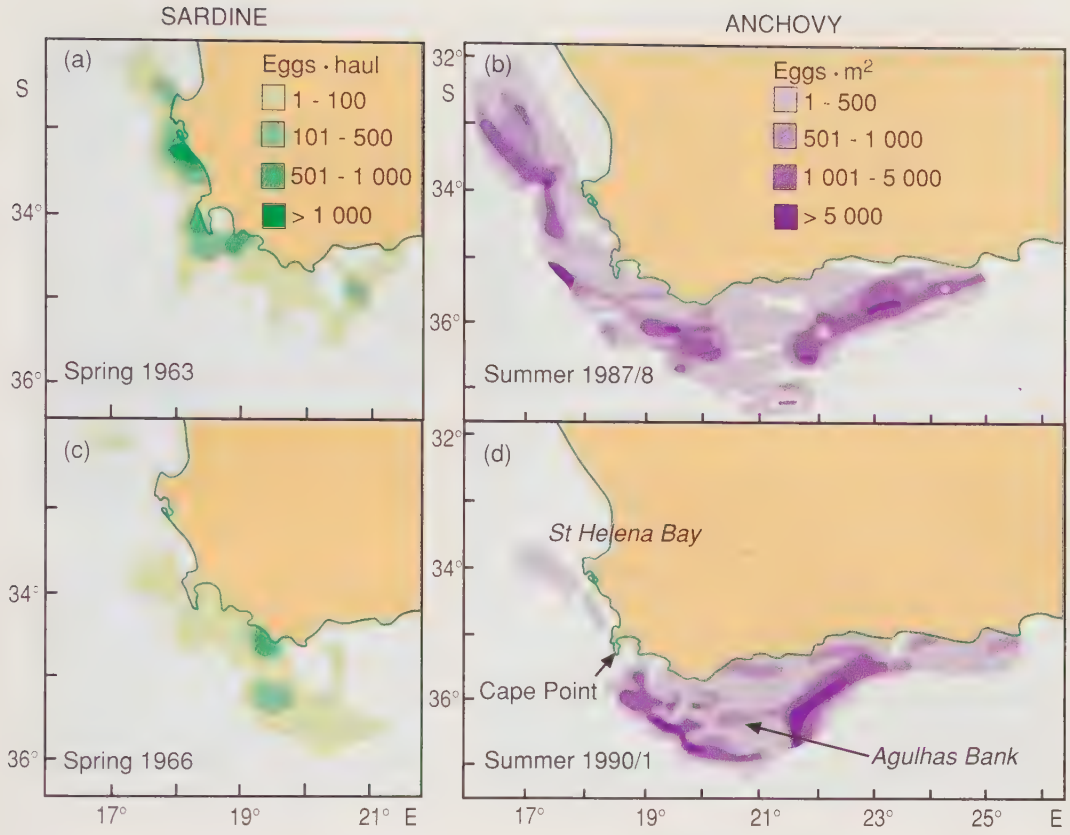

Fig. 15: Extended distribution of (a) sardine and (b) anchovy eggs compared to contracted distribution of (c) sardine and (d) anchovy eggs

flow field based on ADCP data. Results showed that the spatial distribution of anchovy spawners influenced that of anchovy recruits, as well as the location and number of advective losses offshore. There would be heavy losses attributable to offshore advection when spawning is concentrated at the outer edges of the western Agulhas Bank and the 200 m isobath along the South Coast. Few advective losses would occur when spawners are concentrated on the central Agulhas Bank, provided intense spawning does not take place in other areas where young are susceptible to losses offshore. Weak circulation on the Agulhas Bank between September and March, the main transport period, would reduce offshore losses from this region. For the seven years modelled, an average of 45% of recruits were predicted to accumulate in the region between the Orange River mouth and Cape Columbine, a finding supported by the high numbers of recruits traditionally found in the St Helena Bay region. However, passive transport may also be supplemented by active swimming by anchovy of four months and older eastwards out of the north-flowing jet current and into the nursery areas.

While the South African anchovy population has undergone large fluctuations during the past decade, the sardine population, which "crashed" in the mid-1960s, has shown signs of recovery. Modelling was used to compare the spawning, transport and survival of young stages of anchovy and sardine. As the areas over

which adults spawn varies, two years of contrasting distributions were selected for each species (Fig. 15). Results showed that, when advective losses are excluded, survival of young stages would be higher for anchovy than for sardine. However, when transport by currents is included, anchovy were found to spawn in regions more susceptible to advective losses, such as the outer regions of the Agulhas Bank. Advective losses would also be greater when anchovy and sardine spawning is restricted to the Agulhas Bank and South Coast than when it is more widely distributed.

This modelling study has highlighted the role of advection in survival and recruitment of pelagic fish. It has also made a preliminary attempt at addressing some of the differences between sardine and anchovy spawning and subsequent transport of eggs and larvae in South African waters. Further comparisons should be undertaken to improve understanding of shifts in the dominance of pelagic fish species, which will require research on developmental and survival rates of the early life stages. This would facilitate further analysis of environmental influences on these two species.

Investigating fluctuating catch rates of Agulhas sole

The Agulhas sole *Austroglossus pectoralis* is subject to fluctuating seasonal and interannual catch rates which present a problem in economic exploitation for commercial trawlers. A better understanding of the factors that influence these changes in catch rates may not only assist the trawling industry, but also lead to improved management of the fishery. Changes in catch rates are often used in stock assessment models as an index of changes in abundance, but for Agulhas sole such fluctuations are rather a reflection of their availability on the trawling grounds. The Institute therefore launched a preliminary investigation to provide a framework for future research on relevant factors affecting seasonal and interannual changes in catch rates.

Catch rates change with depth and sediment type, being highest at depths less than 75 m and on muddy and sandy sediments. They usually peak in autumn-winter, decline in spring, improve slightly in early summer, and decline again in late summer (Fig. 16). Wind direction also influences catch rates, which increase when offshore (north-westerly and north-easterly) winds predominate and decline when the wind direction changes to predominantly onshore (south-easterly and south-westerly). In the period 1983–1995, catch rates in autumn-winter (April-July) were somewhat higher during years of strong winter north-westerlies.

Spatial changes in catch rates gave some insight into seasonal migration patterns. Catch rates increase as sole move inshore and westwards onto the trawling grounds in late autumn, and decline as the fish move offshore and eastwards in spring and summer (Fig. 17). There are no strong tides or bottom currents on the inner central Agulhas Bank to influence migration, and gradients in bottom-water temperature or dissolved oxygen did not satisfactorily explain the direction of these migrations, which appeared to be unrelated to spawning.

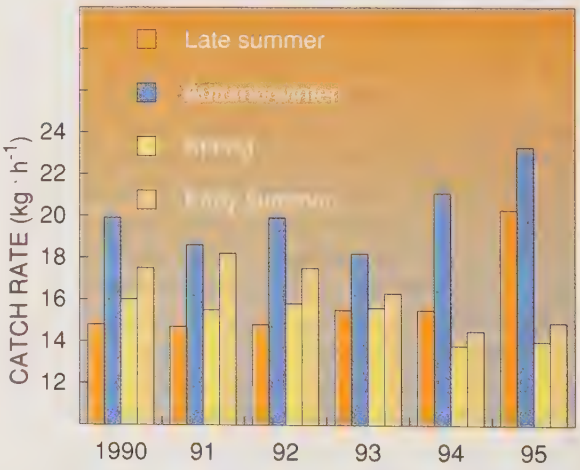

Fig. 16: Seasonal changes in catch rates of Agulhas sole

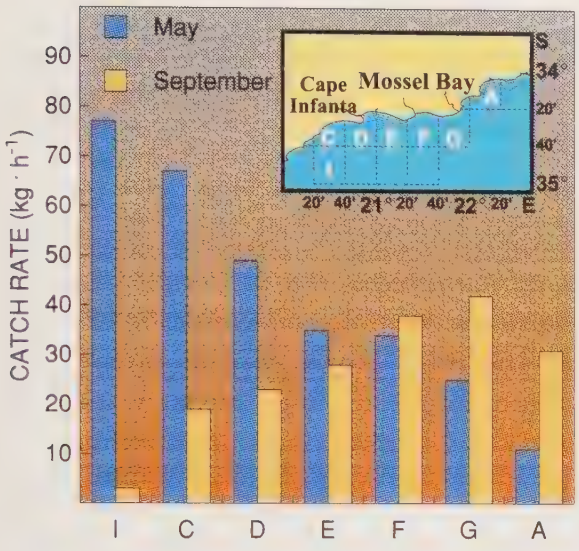

Fig. 17: Spatial changes in catch rates of Agulhas sole in seven blocks with medium to high catches during May and September 1990

Further research is needed to establish the mechanism whereby Agulhas sole respond to changes in wind direction and strength. A directional response to variation in ambient noise should be investigated, as well as the effects of turbidity, wave height, wave breaking, destratification of the water column, upwelling and downwelling.

Determining the target strength of chokka squid

Direct assessment of squid biomass would improve management of the resource, but as yet it has proved unachievable. This is not only because squid aggregations are very mobile, but because little is known about the morphology, behaviour, distribution and quantitative dynamics of these short-lived animals. Furthermore, the target strength of squid, which must be known before biomass can be assessed hydroacoustically, has been poorly investigated. A project was therefore initiated to determine the target strength of the chokka squid *Loligo vulgaris reynaudii*.

One of the primary problems associated with performing *in situ* target strength measurements on live animals is the design of the enclosure, which must remain acoustically transparent and yet be robust enough to withstand the considerable stresses experienced during over-the-side operations and attacks by large predators. The dimensions of the enclosure are determined primarily by the frequency of operation of the transducer, its pulse duration and beam width. Other less quantifiable factors, such as the behaviour of the species in captivity, must also be considered.

Tank tests were conducted to determine the acoustic suitability of material for the enclosure, and a robust plasticized net with a 20 mm square mesh was selected. A 120 kHz transducer with a 9° beam width was suspended 1 m above the net, which was 1.8 m wide and 4 m long. The net was positioned just below the sea surface and live squid introduced through a removable panel, after which the assembly was lowered to a depth of 5–10 m and allowed to stabilize before measurements began. A pulse duration of 0.3 ms was set on the transducer and frequent calibrations were performed, using a 23 mm copper calibration sphere which was placed in the net at the approximate depth maintained by the live squid during the target strength experiments.

An underwater housing containing a low-light, closed-circuit tv camera was positioned below the net to allow squid behaviour to be observed during the experiments. In addition, a numeric display, synchronized to count the echosounder transmissions, was mounted in front of the camera to monitor the swimming behaviour of squid and compare this to the measured backscattter obtained from the echosounder. After each recording session, squid were removed from the enclosure, weighed and measured. Female squid had an average mass of 113 g and an average target strength of -47 dB, whereas males averaged 544 g and -40.6 dB respectively (Fig. 18).

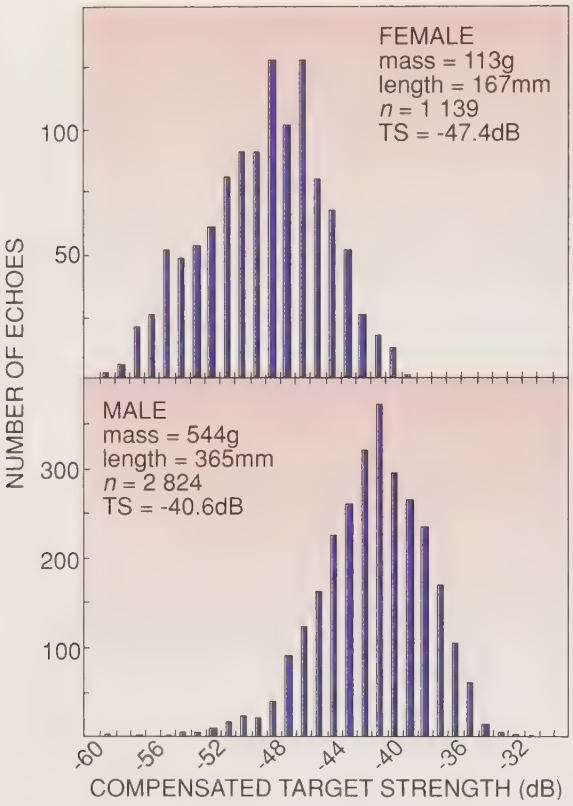

Fig. 18: Target strength experiments revealed considerable variation between individual chokka squid

Future work will focus on solving some of the methodological problems encountered and expanding the existing target strength database, which will be used to investigate various types of squid spawning concentrations. Once this has been achieved, the ability to use hydroacoustic methods for the direct stock assessment of chokka squid will be a step closer.

Exploring a new approach to biodiversity

Three separate developments during 1996 have led to the consideration of a more committed approach to biodiversity management at the Institute. First, with the collapse of a number of fisheries worldwide came recognition that a single-species management approach has overlooked growing problems in ecosystem structure and function. Catch limits are usually based on estimates of fish abundance and age structure, but the resilience of fish populations to continuous exploitation is likely to be vulnerable to changes in ecosystem structure, the destruction of habitat and genetic changes in the stock. Furthermore, whereas catch limits are size- and species-specific, fishing gear is relatively unselective, with the result that undersized and unwanted species are dumped in large numbers at sea. Eutrophication and the introduction of alien species, both of which can lead to an increased incidence of toxic algal blooms and fish diseases, are also cause for concern. A broader view of ecosystem functioning is therefore needed to prevent catastrophic losses in fishery production and negative effects on human health.

Second, a task group set up by the South African Network for Coastal and Oceanic Research (SANCOR), which includes several Institute scientists, has recommended an urgent revision of the management of South Africa's marine protected areas (MPAs), which at present are unevenly distributed, are lacking clear objectives, and are subject to compromised regulations and poaching. Instead, MPAs should play a leading role in the conservation of biodiversity, the management of fisheries and the control of human activities. The task group advised that a national programme be established to develop partnerships with provincial authorities and ensure that MPAs are managed effectively.

Third, South Africa has ratified the Convention on Biological Diversity, and is developing its own policy on biodiversity. As the principal authority below the high-water mark, Sea Fisheries may be tasked with implementing the policy in the marine environment, and an ecosystem approach and a network of MPAs are both integral components of the new Marine Fisheries Policy. Also needed are ecosystem monitoring and education programmes, an

audit of marine biota, which will require advanced taxonomic expertise, and the development of management capacity to conserve biodiversity.

The formation of a broad-based biodiversity working group at the Institute, incorporating both in-house and external expertise, has been proposed to implement a biodiversity policy for the marine environment, as well as to promote multispecies fishery management and improved management of MPAs.

Monitoring the African penguin population

During 1996 initiatives were launched to review the conservation status of South Africa's seabirds using criteria adopted by the IUCN Species Survival Commission. In terms of these criteria, a species is regarded as "Vulnerable" if its population has decreased by more than 20% in the last three generations. This means that it is considered to be facing a high risk of extinction in the wild in the medium-term future. The first species to be addressed was the African (Jackass) penguin *Spheniscus demersus*, which in recent years has decreased by 13% per generation as a result of competition with fisheries and other predators for food, competition with seals for breeding space, and oiling. It therefore warrants classification as vulnerable.

In 1994, about 10 000 penguins were oiled at Dassen and Robben islands after the sinking of the *Apollo Sea*. About half of these were cleaned and returned to the wild, but the rest died. During the following two years, the Institute cóllaborated with the University of Cape Town's Avian Demography Unit and various conservation agencies to monitor the rehabilitation of the cleaned penguins. Of 4 076 birds released with flipper bands, 2 652 (65%) had been resighted at breeding colonies by August 1996, two years after release (Fig. 19). Only 25 (0.6%) had been reported dead by the public, which is less than the average reporting rate for unoiled penguins banded in the wild. This indicates minimal post-release mortality of the rehabilitated penguins, in contrast to the situation in the northern hemisphere, where the average post-release survival period of seabirds cleaned following oiling was found to be just six days.

The Institute also monitored the impact of the *Apollo Sea* oil spill on the populations of African penguins at Dassen and Robben islands. At Dassen Island there were decreases after 1994 in the numbers of African penguins breeding in areas where oil had washed ashore, but increases in some other areas not affected by oil. The most plausible explanation for this is recruitment of new breeders to the breeding population. The nett effect is that the breeding population at Dassen Island has remained relatively stable since 1994, with recruits to the colony offsetting losses to oiling.

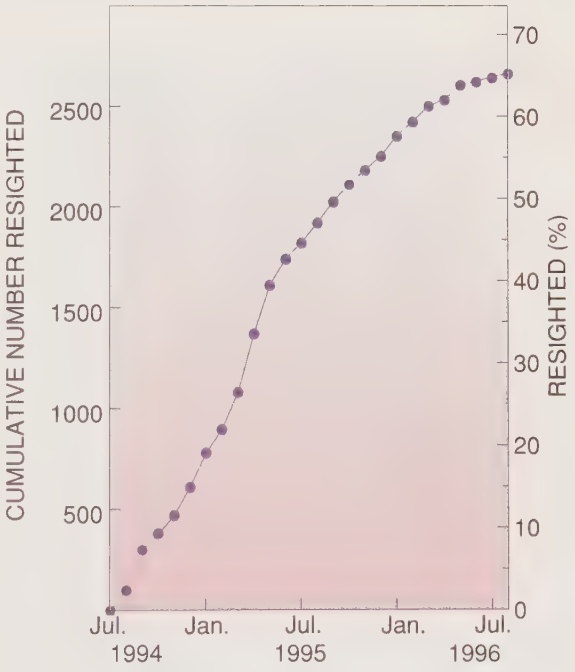

Fig. 19: Number of African penguins banded and released after the Apollo Sea *oil spill that were resighted during the following two years*

At Robben Island, there was a decrease of about 500 breeding pairs between 1994 and 1995, which matches the expected loss of birds to oiling. In 1996 and 1997 the breeding population increased (Fig. 20), attributable to recruitment of first-time breeders to the colony. Modelling has shown that the increase of the Robben Island colony is too rapid to be sustained by breeding alone; instead, at least 60% of new breeders at Robben Island are believed to be immigrants. Resightings of banded birds have revealed that about two-thirds of these are from Dyer Island and most of the rest from Dassen Island.

Penguin populations to the south-east of the Cape Peninsula, which flourished during the period of anchovy dominance (1970s), have been decreasing, whereas those to the north, which prospered when sardine predominated (1950s) but underwent severe decreases during the anchovy regime, have stabilized or increased. This corresponds with the recent shift in dominance in the pelagic ecosystem from anchovy to sardine. This shift was initiated in the early 1980s, coinciding with the establishment of three new colonies of African penguins in the vicinity of the Cape Peninsula.

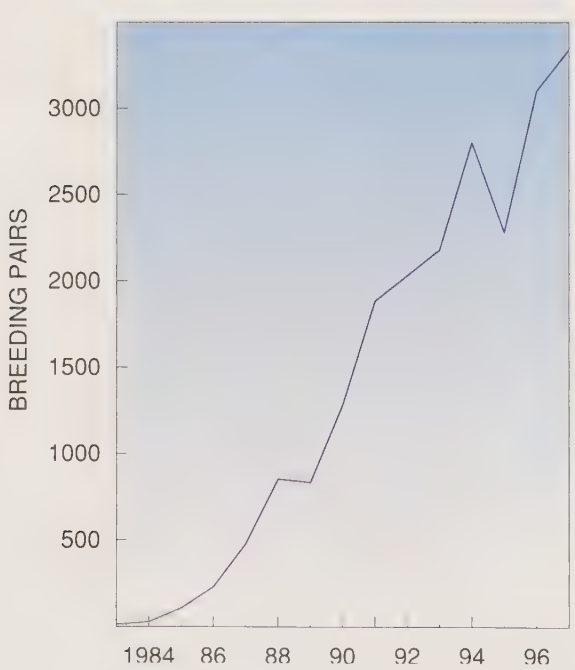

Fig. 20: Trends in the breeding population of African penguins at Robben Island, 1983-1997

Studying the Heaviside's dolphin

The Heaviside's dolphin *Cephalorhynchus heavisidii* is the only indigenous dolphin found on the west coast of southern Africa, its distribution extending from Cape Point to southern Angola. It is a small dolphin averaging 1.5 m in length, and is usually found close inshore in small groups of one to five animals. However, little is known about its status or ecology.

In February 1997 the Institute initiated a project to investigate the species' movements, habitat utilization and foraging behaviour, using satellite and VHF tags. Two males and one pregnant female were captured near Elands Bay using a specially designed "break away" head net, and fitted with satellite-linked time-depth recorders (TDRs) attached to custom-made dorsal fin saddles. Two of the saddles also contained small VHF radios so that the animals could be tracked at sea with hand-held portable receivers. The saddles were attached with Delrin pins and magnesium nuts, which corrode rapidly in seawater and are designed to release the instrument after about two months.

Attempts to follow the animals using signals from the VHF transmitters proved unsuccessful, as the surfacing time of the dolphins was too brief for them to be located. Instead, reliance had to be placed solely on the data supplied by the ARGOS satellite-receiving station in France. By the time these data reached Cape Town they were at least 24 hours old, and so were of limited use in enabling the research ship to approach the dolphins.

The satellite locations for one of the adult males revealed that, during a five-week period, it

Fig. 21: The Heaviside's dolphin is endemic to the west coast of southern Africa

remained within St Helena Bay, bounded by Elands Bay in the north and Paternoster Point in the south. This suggests that the species is a local resident with a limited home range. Few data are available for the pregnant female, but she appeared to be traversing the coastline close to shore.

The dive data revealed no apparent diel pattern in the depth or duration of dives, as most were shallow and of short duration, regardless of time of day. However, during daylight most dives were only 2–4 m deep and never more than 60 m deep during the observation period, whereas at night they tended to be slightly deeper (4–10 m) with a maximum recorded depth of 104 m and a dive duration of more than nine minutes.

This pilot study has shown that Heaviside's dolphins can be captured and fitted with satellite tags without injury, laying the groundwork for future research into this little-known species.

Conducting research in the Southern Ocean

Research in the Southern Ocean is undertaken by the Institute in support of South Africa's obligations to the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR). Part of this research focuses on the resource potential of Antarctic krill *Euphausia superba*. In co-operation with scientists at the University of Cape Town, the Institute is developing models of krill spatial distribution which are used in managing the krill fishery and studying krill predator-prey relationships.

The Institute also conducts a seabird monitoring programme at Marion Island as a contribution to the CCAMLR Ecosystem Monitoring Programme (CEMP). The sub-Antarctic Prince Edward Islands, which include Marion Island, support four species of penguin, with some

Fig. 22: Trends in the numbers of (a) clutches laid by rockhopper penguins, 1983/84–1995/96 and (b) chicks fledged per clutch for macaroni penguins, 1979/80–1995/96

400 000 pairs of the macaroni penguin *Eudyptes chrysolophus* and about 150 000 pairs of the rockhopper penguin *Eudyptes chrysocome*. Trends in the size of the breeding population and in breeding success have been monitored annually at selected colonies since the 1979/80 summer season for macaroni penguins and the 1983/84 season for rockhopper penguins.

The largest of three macaroni penguin colonies investigated decreased in size over the study period while the other two remained stable, although some inter-colony transfer may have taken place. In the case of the rockhopper penguin, the larger two of the three colonies investigated both decreased over the study period, while the other remained stable. Trends in the number of pairs breeding at the three rockhopper penguin colonies (Fig. 22a) were all significantly correlated, suggesting that the proportion of birds breeding may be influenced by environmental conditions. However, the same does not appear to be the case for macaroni penguins.

Seasonal trends in breeding success (Fig. 22b) were significantly correlated in all three inter-colony comparisons for macaroni penguins, but in only one for rockhopper penguins. This suggests that breeding success of macaroni penguins may be influenced by a wider-scale phenomenon, such as food availability within the foraging range, than is applicable to rockhopper penguins. In addition, trends in breeding success, hatching success and chick survival of macaroni and rockhopper penguins were not significantly correlated to each other, suggesting that factors influencing the reproductive performance of the two species are not the same.

Such differences in trends for two closely related species have implications for the use of seabirds as indicators in marine ecosystem monitoring. If the aim is to detect the influence of factors operating at a meso- or macro-scale, the best parameters to monitor will be species specific.

A more recent commitment to CCAMLR involves the identification and collection of essential scientific information needed to manage the fishery on Patagonian toothfish *Dissostichus eleginoides*, which has recently developed in the vicinity of the Prince Edward Islands. Little is known about the potential yield and stock identity of toothfish in the area, so research is aimed at identifying and measuring key parameters that can be used in management models. The Institute has played a key role in designing a CCAMLR exploratory fishery for the region that will allow the necessary data to be collected. Perhaps more important for South Africa, an integrated scheme using scientific observers and satellite-tracking to gather information directly from vessels on the fishing grounds has been deployed for the first time.

TECHNOLOGICAL ADVANCES

Research and development

The Institute's Research Engineering Services (RES) have developed various measuring and sampling devices during the past year, including mini-Bongo plankton nets for use on smaller ships, and a light trap which is lowered into shallow water at night to attract squid larvae. Devices now in the experimental testing stage are the abalone measuring calipers and the pelagic measuring board described in the previous issue of *Research Highlights*.

A trawl warp monitoring system, which measures load, wire out and wire speed, was developed and fitted to FRS *Africana*. A slight deflection is introduced into the cable which runs over three sheaves, the middle one mounted on a fork in contact with a strain gauge. If the load rises above the safe limit of four or five tons, indicating that the net may have caught on a rock, an alarm sounds on the bridge.

Four of the Institute's conductivity, temperature and depth (CTD) units were rebuilt as Mark 3C CTDs at General Oceanics, Miami, and two of them fitted with oxygen sensors. The deck units on *Africana* and *Algoa* have been converted to use commercially available data acquisition software, a world scientific standard. Also installed recently were a precision thermometry bridge, two temperature-controlled baths, three salinity baths and two triple point cells which provide precise calibration points for the change of phase from solid to liquid. Such technology places the Institute in line with the highest standards of precision in physical hydrographic sampling.

A new way of transmitting data from an underwater unit to the surface, developed by RES and described in the previous issue of *Research Highlights*, enables data on fluorescence, turbidity, light and any other measurement done *in situ* to be multiplexed with the CTD data and displayed simultaneously on board, a great advantage when deciding where to take water samples.

Satellite tracking of fishing vessels

Research into the application of vessel monitoring systems (VMS) as a means of monitoring fishing vessels was initiated in South Africa during 1996. The development of new fisheries on deep-water resources, and the inception of the longline-directed fishery for Patagonian toothfish in the Southern Ocean, have meant that for the first time fishing operations are moving across South African fishing boundaries into international waters, including areas controlled by CCAMLR. South Africa followed worldwide trends by prescribing the use of satellite tracking as a means of monitoring and control.

Two systems are currently being tested by the Institute. The locally developed tracking units, using global positioning systems (GPS) linked to the International Maritime Satellite Network (INMARSAT), consist of a small tamper-proof unit installed on the bridge of a vessel with independent GPS and INMARSAT-C transmitters. Real-time positions of the vessel are obtained at the Institute's base station, showing a detailed track (Fig. 23) that discriminates between the various activities of fishing, trawling, line-setting and steaming. The reporting frequency can be changed from the base station, and units can also be "interrogated" to learn more about environmental conditions (such as ambient temperature, wind speed and sea state), the frequency of hauling lines or trawls, or whether cargo is being off-loaded onto another

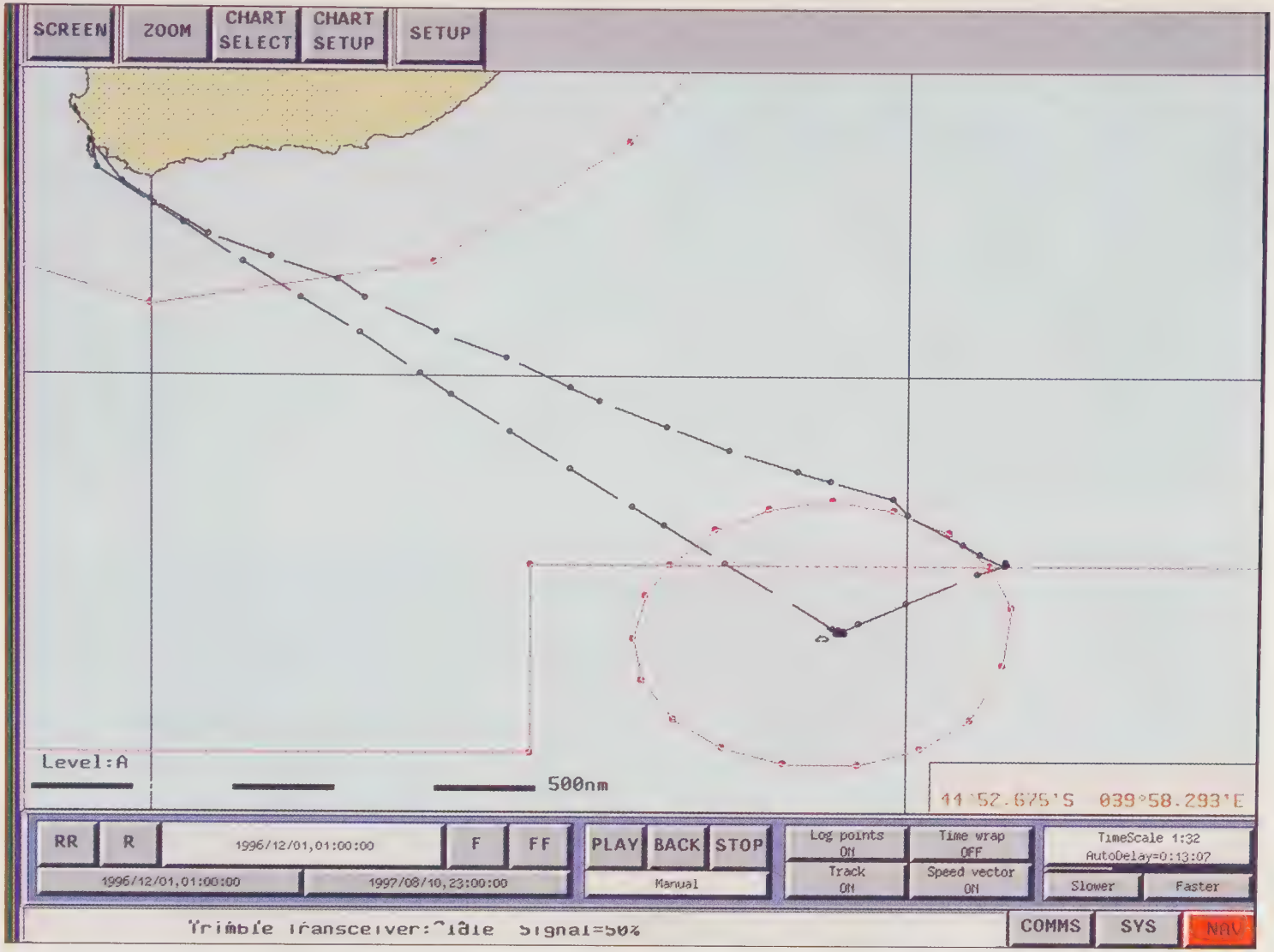

Fig. 23: A simplified output from a satellite-tracking system, showing the vessel's track, the Exclusive Economic Zones around South Africa and the Prince Edward Islands, and the boundary of the CCAMLR-controlled area

vessel. Tampering is reported immediately, and power disconnection or failure is backed-up by a three-hour battery supply.

The second system being tested is the less complex ARGOS satellite and reporting system, based in France. The units automatically report vessel positions at prescribed intervals, and can also be used for simple communications with the base station, such as relaying reports of catches.

The acoustic capability of the FRS *Africana* received a boost last year with the implementation of a new scientific hydroacoustic system, based on the Simrad EK500 model of echosounder. The main characteristics of this echosounder, which replaces the EK400, are a 160 dB dynamic range (which prevents receiver saturation), independent processing of up to three frequency channels, and powerful data interfaces for external data-logging and processing. This is conducted using the Simrad EP500 post-processing system, which replaces the successful AIDA system developed at the Institute.

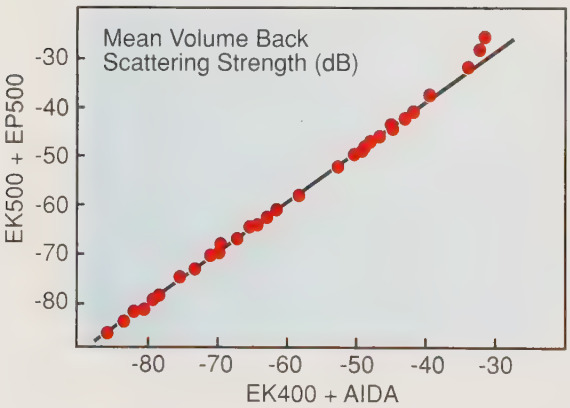

Fig. 24: Comparative performance of the old and new hydroacoustic systems showing similar sensitivity within the range of signals tested

The system's main advantage is that it is implemented in a Windows 95, PC-based network, which connects the EK500 unit with a data-logging PC, a data-processing PC, a colour printer, a monochrome laser printer and a WORM (Write Once Read Many) CD-recording system. The PCs can access each other's hard disk drives, facilitating data analysis and storage. This was a requirement when the system was devised, as it can generate up to 5 Mb of information per frequency per hour. Once ashore, the archived data can be displayed in the form of a colour echochart at any PC with CD-ROM capabilities.

Before full implementation, comparisons were carried out between the old and the new systems, showing remarkably similar sensitivity responses (Fig. 24). The new system was tested at sea during the pelagic pre-recruitment cruise in March 1997, and fully implemented during the pelagic recruitment cruise in June 1997. The acoustic facilities of the FRS *Algoa* will also be upgraded with the new model in due course.

PUBLICATIONS

In 1996 Sea Fisheries was involved in 196 publications, oral papers and posters. This is 33 more than the previous year and can be largely attributed to the two symposia held in Cape Town in November 1996. The Institute was also well represented at an international penguin conference, a phycology symposium and a workshop on South African sardine. In addition, the 17th volume of the *South African Journal of marine Science*, under new editorship, was published.

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